



# CONTEMPORARY MILITARY GEOSCIENCES

in South Africa

Hennie Smit  
Jacques Bezuidenhout  
*Editors*

*Contemporary Military Geosciences in South Africa*

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SUN PRESS





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# List of Acronyms and Abbreviations



3D	Three-dimensional
46 SA Bde	46 South African Brigade
6 SAI	6 South African Infantry Battalion
ABS	Antilock Braking Systems
ADF	Allied Democratic Forces
AHP	Analytical Hierarchy Process
AIMS 2050	Africa's Integrated Maritime Strategy 2050
ASL	Above Sea Level
AU	African Union
BCC	Benguela Current Convention
BCLME	Benguela Current Large Marine Ecosystem
CAMMS	Condensed Army Mobility Model System
CGA	Centre for Geographical Analysis
CI	Cone Index
CSIR	Council for Scientific and Industrial Research
DAC	Department of Arts and Culture
DEAT	Department of Environmental Affairs and Tourism (South Africa)

DEM	Digital Elevation Model
DEO	Designated Environmental Officer
DoDMV	Department of Defence and Military Veterans (South Africa)
DRC	Democratic Republic of Congo
DSS	Decision Support System
DTM	Digital Terrain Model
EA	Environmental Auditing
EBR	Environmental Baseline Report
ECR	Environmental Closure Report
EEZ	Exclusive Economic Zone
EIP	Environmental Implementation Plan
EMF	Environmental Management Facility
EMP	Environmental Management Plan
EMS	Environmental Management System
EOS	Equations of State
ERF	Environmental Review Forum
ERs	Environmental Representatives
ESWG	Environmental Security Working Group
FBDM	Frances Baard District Municipality
FEA	Finite Element Analyses
FOSSGIS	Free and Open Source Software Geographic Information Systems
FSA	Full Spectrum Analyses
GDP	Gross Domestic Product
GIS	Geographic Information Systems
GIT	Geographical Information Technology
GMI	Grahamstown Military Installation
GNSS/GPS	Global Navigation Satellite System
IAEA	International Atomic Energy Agency
ICAO	International Civil Aviation Organisation
IHO	International Hydrographic Organisation
ILH	Imperial Light Horse
IMO	International Maritime Organisation
IPB	Intelligence Preparation of the Battlefield
ISPS	International Ship and Port Security



IUU fishing	Illegal, Unreported and Unregulated fishing
LFOPC	Leap-Frog Algorithm for Constrained Optimisation
LGI	Laboratory for Advanced Engineering
LMT	Land Mobility Technologies
LNG	Liquefied Natural Gas
LTS	Link-Tracing Sampling
MBD	Multi Body Dynamics
MCA	Multi-Channel Analyser
MCE	Multiple-Criteria Evaluation
MC00	Modified Combined Obstacles Overlay
MDA	Maritime Domain Awareness
MDAC	Maritime Domain Awareness Centre
MIEM	Military Integrated Environmental Management
MMP	Mean Maximum Pressure
MMPSim	Mean Maximum Pressure Simulation
MOBSIM	Mobility Simulations
MONUSCO	United Nations Organization Stabilisation Mission in the Democratic Republic of the Congo
MRCC	Maritime Rescue Coordination Centre
MSC	Maritime Security Centre
MTA	Military Training Area
NATO	North Atlantic Treaty Organisation
NATO-CCMS	North Atlantic Treaty Organisation Committee on the Challenge of Modern Society
NDT	National Department of Tourism
NG-NRMM	New Generation NATO Reference Mobility Model
NHCTS	National Heritage and Cultural Tourism Strategy
NRMM	NATO Reference Mobility Model
PDA	Personal Data Assistant
RAMC	Royal Army Medical Corps
RCI	Remoulded Cone Index
REC	Regional Economic Community
RFIM	Regional Facilities Interface Management
RI	Remoulded Index
RideCom	Ride Comfort

RN	Royal Navy
RNVR	Royal Naval Volunteer Reserve
SA	South Africa
SA Army	South African Army
SAACTC	South African Army Combat Training Centre
SAAMM	South African Army Mobility Model
SADC	Southern African Development Corporation
SAIHC	Southern Africa and Islands Hydrographic Commission
SAMSA	South African Maritime Safety Authority
SAN	South African Navy
SANDF	South African National Defence Force
SANHO	South African Navy Hydrographic Office
SAT	South African Tourism
SCR	Site Closure Report
SEWing	Strategic Environmental Working Group
SMA	Saldanha Bay Military Area
SPLM	Sol Plaatje Local Municipality
SUDEM	Stellenbosch University Digital Elevation Model
UN	United Nations
UNAMID	United Nations Mission in Darfur
UNDP	United Nations Development Programme
UNWTO	United Nations World Tourism Organisation
USA DoD	United States Department of Defence
USA GAO	United States of America Government Accountability Office
USA	United States of America
VBA	Visual Basic for Applications
VBDrive	Visual Basic Drive
VCI	Vehicle Cone Index
VehSim2D	Vehicle Simulation 2D
VLCI	Vehicle Limiting Cone Index

# Foreword



## Book Editors

The editors want to thank all the contributing authors for their meticulous research and dedication to guarantee chapters of the highest scientific merit, as well as their efforts to ensure that publication timelines were kept. We would also like to extend our sincere gratitude to the anonymous external reviewers for their helpful, insightful and critical academic evaluation of the manuscript. The comments and suggestions emanating from the double-blind peer review mechanism were an indispensable part of the process to enhance the academic quality and integrity of the publication. In the final instance, we want to express our heartfelt gratefulness to Emily Vosloo and Anina Joubert from AFRICAN SUN MeDIA who patiently guided us through the publication process. We hope that this publication will lead to a better understanding and appreciation of the scope and diversity of military geoscientific research.

*Hennie Smit and Jacques Bezuidenhout*  
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# Introduction



Military Geosciences comprises all disciplines with an interest in military activities within a geological, geographical or, more generically, spatial context. The research focus is thus firmly on how space influences the military, how the military use space and how space is impacted upon by military activities. These research activities aim to enhance our understanding of military activities and ultimately to mitigate the impact of military activities on the bio-physical, socio-cultural and socio-economic environments in which the military operates. *Contemporary Military Geosciences in South Africa* aims to showcase both the diversity and coherence of military geoscientific enquiry in South Africa with eight chapters of diverse topics, united by a common military, spatial and South African focus.

South Africa has a long military history that ranges from internal conflicts to colonial wars, both the World Wars and most recently the Angola-Namibian border conflict. This has resulted in South Africa developing a relatively large and modern defence force, as well as an extensive defence industry that supports and develops military hardware. Most of the military operations were conducted on land and the South African Defence industry consequently mainly focused on supporting the army and air force. *Contemporary Military Geosciences in South Africa* will therefore mainly focus on military geoscientific research in South Africa that is aimed at terrestrial operations, with the exception of Chapter 5 which addresses the South African maritime domain.

The book is divided into four parts – each reflecting a different aspect of military geoscientific research.

## **PART 1 ● Historical Battlefields**

The rich military history of South Africa left its mark on the South African landscape in the many readily accessible and in some cases, well-preserved battlefields. Many of these sites were and are important in the cultural identity of certain groups in South Africa. A portion of the population was also subjected to conscription during the Namibian Angolan border war, which resulted in an appreciation for historical military activities. Especially the Anglo-Boer War battle sites attract a significant number of visitors on a yearly basis. These factors resulted in a substantial growth in battlefield tourism and associated activities in South Africa. A contemporary look at battlefield archaeology and the heritage of the Second Anglo-Boer War, as well as the tourism potential of battlefield sites showcases this interest in South African battle sites in the first part of the book.

## **PART 2 ● Military Environmental Management**

Many modern military challenges extend well beyond the battlefield and commonly include developing strategies to increase environmental sustainability of military installations, as well as numerical modelling of complex terrestrial processes, all with the aim of addressing specific military issues. Terrestrial military conflicts have an immense impact on the natural environment and the South African military soon realised that a Military Environmental Management strategy was needed. With the global emphasis on sustainability and proper environmental management as background, part two focuses on the challenges of monitoring the implementation of military environmental management and presents a special decision support system for military integrated environmental management.

### **PART 3 • The Maritime Domain**

As South Africa achieved greater independence from Great Britain during the first part of the last century, this affected the development of its military forces and specifically the South African Navy. Participation in the Second World War, as well as close cooperation with the Royal Navy shaped the function, as well as the equipment of the maritime force, while the Cold War and political ideology further shaped the operational availability and mandate. The end of the Cold War, a changing political landscape and the perceived increase of maritime threats set the scene for renewal and changes of mandate. Part three provides an in-depth analysis of the Southern African Maritime domain, focusing on the changing threats, as well as measures to mitigate such threats in the maritime domain.

### **PART 4 • Terrain**

The African Savanna environment created challenges unique to the African domain and equipment had to be adapted and developed to address this. The fairly recent low-intensity, semi-conventional Angola-Namibian Border conflict took place in such an environment. Part four concludes the book with three chapters that focuses on terrain negotiability, mobility modelling software and how geographic factors can be modelled or determined through remote sensing.

THE EDITORS





# PART 1

Historical Battlefields

# Perspectives on Battlefield Archaeology and Heritage of the Second Anglo-Boer War



Jasper Knight & David Passmore



## Introduction

Archaeological interest in the conflicts of the mid-late 19<sup>th</sup> and 20<sup>th</sup> century has become well-established in recent years and is increasingly informing the management practices and visitor experience of associated heritage monuments and landscapes. Most attention has focused on the large-scale conflicts of the United States of America (USA) Civil War [1861-1865],<sup>1</sup> First World War [1914-1918]<sup>2</sup> and increasingly Second World War [1939-1945].<sup>3</sup> However, studies in regions as diverse as Paraguay,<sup>4</sup> New Mexico,<sup>5</sup> Cuba,<sup>6</sup> Libya,<sup>7</sup> Germany<sup>8</sup> and Africa<sup>9</sup> now demonstrate that ideas in conflict archaeology and military heritage can be applied to smaller scale and more recent conflicts. These studies are significant because they provide evidence for the evolution of weapons, tactics and modes of warfare in different settings and contexts and they also highlight the broadening of conflict archaeology's interest in the signature of warfare both on and beyond the battlefield.<sup>10</sup>



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The Second Anglo-Boer War, fought between the independent Boer Republics and Great Britain between October 1899 and May 1902, has particular potential in this respect. One of the first military conflicts fought with recognisably modern weaponry, it foreshadowed the many guerilla-type campaigns of later wars.<sup>11</sup> It also has the dubious distinction of being one of the earliest conflicts to implement large-scale internment of civilian populations – a practice established by the Spanish in Cuba during the late 19<sup>th</sup> century and adopted by the British in South Africa.<sup>12</sup> However, the long record of academic interest in the Anglo-Boer War by historians and social scientists is not matched by the comparatively few published accounts of the archaeological record of this conflict.<sup>13</sup> In particular, there is an absence of battlefield archaeological surveys, despite the many and varied battles and skirmishes and their geographical spread across the country.<sup>14</sup>

To date, most of the archaeological sites associated with the Anglo-Boer War that have been reported in the literature are derived from limited, non-invasive surface surveys of extant features and artefact scatters, rather than large-scale and/or detailed excavation. Archaeological investigations of conventional military sites are restricted to fortifications built to defend Pretoria and occupied by the British during the war,<sup>15</sup> and deposits of domestic activities associated with a British outpost in what is now the Kruger National Park.<sup>16</sup> There is a striking absence of archaeological evidence reported from battlefield or skirmish sites, although some stone walls built on hilltops overlooking the Limpopo River in the Mapungubwe area have been attributed to Boer military activity during early phases of the war.<sup>17</sup> There have also been studies on the impacts of military activities on surrounding civilian communities. This includes archaeological evidence for a concentration camp and (immediate post-war) orphanage and school for Afrikaner women and children, respectively, at Irene, Gauteng,<sup>18</sup> and refugee graffiti in a rock shelter at Telperion, Mpumalanga.<sup>19</sup> There is also archaeological evidence for a refugee camp and associated cemetery for the indigenous black population at Brandfort, Free State,<sup>20</sup> and a solitary burial of a black participant in the British military near Dundee, KwaZulu-Natal.<sup>21</sup> Named sites are located on figure 1.1.

Despite limited archaeological evidence, Anglo-Boer War battlefield sites have been the focus of post-war commemorative activity, with many sites exhibiting grave markers, memorials and monuments. As such these battlefield landscapes represent important sites of heritage and memory and are linked to wider narratives of national identity and sense of place.<sup>22</sup>

The purpose of this study is to explore the multidimensional contexts of Anglo-Boer War archaeology, heritage and memorialisation, drawing on evidence from two well-known



battlefield sites of Colenso and Spioen Kop. (There are various spellings of the latter site.) At these sites, the locations of different features within the landscape were mapped using a handheld Global Navigation Satellite System (GPS) and observations on physical and human landscape features were recorded. These features were interpreted based on evidence from the wider literature in the discipline area of conflict archaeology and on conflict heritage and memorialisation, which is well developed in other parts of the world, but less so in South Africa. In detail this chapter addresses three main topics, which are:

1. the landscape and heritage contexts of Anglo-Boer War sites;
2. how narratives of landscape and heritage are linked together, through considering examples of the battlefield sites at Colenso and Spioen Kop; and
3. overarching themes of conflict and battlefield archaeology and heritage.

Discussion of these points is set within the specific framework of identity and memorialisation in South Africa, which is somewhat different to that found elsewhere in the world. Potential future research directions are then identified.

## **The Second Anglo-Boer War: the Context of Engagements, Memory, Heritage and Representation**

Military engagements during the Second Anglo-Boer War varied from large-scale battles to guerilla ambushes and sieges. The 43 most well-known battlefield and engagement sites of the war are shown in figure 1.1.<sup>23</sup> These took place in different physical settings (hilltops, river valleys, mountain passes) and under different climatic conditions.<sup>24</sup> Several phases of the war can be identified. Initially (from October 1899), Boer forces advanced into the British territories of Cape Colony and Natal and besieged garrisons at Ladysmith, Mafeking and Kimberley. Boer victories were gained at many sites, in particular in Natal, during this first phase, including at Colenso and Magersfontein. The second phase, beginning in 1900, was characterised by British offensives to relieve besieged garrisons and then advancing into the Boer Republics of the Orange Free State and Transvaal. Most engagements in the first part of 1900 took place in these territories. The final phase, from mid-1900 to the negotiated peace that ended the war in May 1902, was characterised by mainly guerilla-style raids by Boer troops on British communications and supply routes across the country. These different phases indicate changes in military tactics and styles of engagement as the war progressed and in response to the nature of the landscapes within which combatants interacted. There are also multiple parallel narratives of the war based not only on British vs Boer combatants, but also on other direct and indirect participants, including local Black and

Indian people who were engaged as cooks, drivers, stretcher-bearers and in other roles on both sides and citizens of other countries who were soldiers in the British or Boer forces.<sup>25</sup> Many of these narratives remain untold.

Anglo-Boer War sites of engagement – whether by large-scale battles or short skirmishes – are manifested in the modern landscape by features ranging from large built structures to minor modifications of the natural terrain. The most imposing features include forts, fortified buildings and other structures associated with rear-area military activity. These are most common in urban areas, but many blockhouses were built to secure supply and communications routes during the final phase of the war.<sup>26</sup> The signatures of rural battles and engagements, by contrast, may include field fortifications such as trenches and breastworks, but often take the form of post-war grave markers and memorials. All such places and features, including battle sites with no visible evidence of conflict, are sites of potential heritage value. The status, interpretation and management of conflict landscapes in respect of national and international heritage resources have been the focus of a rich and multidisciplinary literature.<sup>27</sup>

Anglo-Boer War sites, in the context of post-1994 South Africa, have a contested contemporary heritage,<sup>28</sup> but some are formally protected as archaeological sites under the terms of Section 35 of the South African National Heritage Resources Act 1999 (Act No 25 of 1999, effective from 1 April 2000). Graves are covered under Section 36 of this act and also by the Commonwealth War Graves Act 1992 (Act No 8 of 1992). At present there are no Anglo-Boer War sites featured in the list of 24 National Heritage Sites, but among the many hundreds of Provincial Heritage Sites there are at least 49 that are directly or indirectly associated with this period. The majority from this period are buildings, either of military origin (27 examples, especially blockhouses but also including forts and powder magazines) or re-purposed civilian structures (14 examples, including buildings used as hospitals, storehouses and mess facilities). Other sites include six cemeteries (of which four are dedicated to women and children who died in concentration camps established during the war), five memorials or symbolic buildings and a single example of a concentration camp at Uitenhage in the Eastern Cape. Of the 43 most well-known battlefields and engagement sites of the Anglo-Boer War,<sup>29</sup> only five have been recognised as Provincial Heritage Sites, at Spioenkop, Talana, Platrand and Elandslaagte (all in KwaZulu-Natal) and at Magersfontein in Northern Cape.

Although the majority of Anglo-Boer War sites fall outside these formal heritage designations, they constitute important symbols of past events and have wider cultural resonance.<sup>30</sup> Memorials and grave markers are covered by Section 36 of the National Heritage Resources Act, but these also provide clues as to the wider identity and associations

of that person, including to a military unit, family or nation. Memorials at sites can also act as the focus for memory, performance and expressions of identity and power for different groups of people through the act of remembrance and can be considered as heritage objects in themselves.<sup>31</sup> Hall lists eight Boer and 52 British Gardens of Remembrance for the Anglo-Boer War.<sup>32</sup>

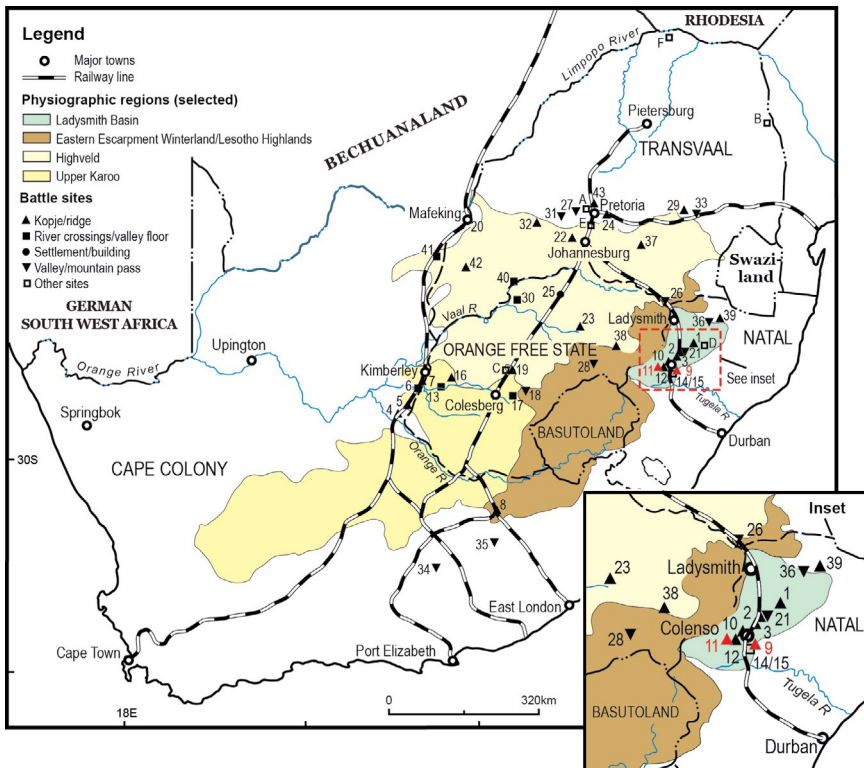


FIGURE 1.1 Location of key sites of engagement during the Second Anglo-Boer War and the physiographic settings (shaded) of these engagements and the main contemporary railway lines. Numbered battlefield sites 1–43 are listed in Passmore et al. [2015]. Particular emphasis in this chapter is placed on case study sites of Colenso (9) and Spioen Kop (11). Additional locations mentioned in this chapter are: A–Fort Daspoortrand, Pretoria; B–Letaba; C–Brandfort; D–Dundee district; E–Irene, Centurion; F–Mapungubwe.

## Case Studies: Colenso and Spioen Kop

Here, we present two case studies that illustrate different aspects of Anglo-Boer War battlefield archaeology and heritage, which are related not only to the different properties and stages of engagement during these battles, but also relate to site-scale geomorphology that provides the wider context of – and in part the explanation for – the nature of the engagement at these sites. The case studies of Colenso and Spioen Kop are useful because the battles are well documented in contemporary accounts and both are important existing heritage sites with different types of touristic information, infrastructure and memorialisation present at the sites.<sup>33</sup> They also provide contrasting examples of the potential for archaeology and heritage activities and, thus, can inform on wider present-day debates on issues of heritage, culture and memory.<sup>34</sup> Here, we briefly summarise the action of these individual battles, today's evidence in the landscape from both archaeological and heritage perspectives and highlight contemporary issues at these sites.

### Colenso

#### *Location and engagements*

The town of Colenso is located along the Tugela River, 20 kilometres SSW of Ladysmith, KwaZulu-Natal (figure 1.1). Strategically, this location affords crossing points of the river via a road bridge (constructed 1879) and railway bridge (constructed 1886). The river itself is relatively wide and deep, even in the dry season, has broad meanders and has some sections such as at Tugela Falls five kilometres north of the town that are mainly bedrock dominated with canyon-like tributaries and shallower bedrock sections along the river channel. Surrounding the town are several isolated hilltops from which there is generally good visibility across the landscape. Contemporary photos showed the landscape to be open and more bare of trees than at present. Military action at Colenso commenced on 15 December 1899 as General Buller led an advancing British force from the south in order to lift the Boer siege of Ladysmith. Buller's attempt to secure river crossings in three places and the hilltop of Hlangwane, three kilometres NE of Colenso, failed in the face of rifle fire from Boer troops located on the north side of the Tugela. A British gun battery position just outside of the town, under Colonel Long, also came under fire and was abandoned. A second British assault on Colenso on 14-27 February 1900 was able to secure hilltop positions south of the river, providing covering fire for pontoon bridge crossings of the river to the north and thence to Ladysmith.

### *Archaeological evidence and memorials today*

Memorial markers were placed at key locations within the town and in the surrounding area within 10-15 years of the battle. These are mainly small (40 centimetre high) concrete blocks with identifying plaques. A good example is the position of markers of Long's guns, now on an area of disused ground near the railway station. As the town developed, many of these sites were incorporated within the growing urban area or threatened by urban expansion and thus in 1962-1964, several markers were removed to a location outside of the town as a dedicated memorial space. This location, the Clouston Garden of Remembrance (4,8 kilometres South of the town, along the R74), not only provides a focus for memorials to combatants, it also occupies a specific location that is relevant to the battle history described below. Several marker stones at the entrance to the site record its history. One states: "In this Garden of Remembrance are buried British soldiers killed at the Battle of Colenso on the 15<sup>th</sup> December 1899. Also some of those killed in actions north of the Tugela during the operations of January and February 1900 and of those who died in military hospitals at Colenso in 1900. Memorials originally erected on the battlefield have also been brought to this Garden of Remembrance". Another states: "This monument originally stood near the site of the British gun positions in Colenso and was moved here in 1964. A marker has been placed on the original site".

The site is split into two areas (figure 1.2). The lowermost area is flat with well-tended grass and a structured, organised pattern of memorials. This represents the more formal part of the garden and contains memorials to key personnel. The uppermost area is on higher, uneven ground, is more rocky and contains indigenous trees and shrubs (which were mostly planted when the garden was established). Bourquin and Torlage call this position Shooter's Hill, located adjacent to a British field hospital position.<sup>35</sup> This uppermost area is arranged in a different way, with meandering (and informal) paths and memorial markers to specific people and engagements, including sites where named combatants died. It is this uppermost part of the site where a British gun emplacement was located, looking over to the town three kilometres to the northeast. The locations of memorials of different types and for different people, provide a viewpoint of the relative perceived importance of these individuals, their power relations and identities.

In the lower garden, 16 different groups of memorials are present, covering a range of combatants and military units as shown in figure 1.3. The simplest memorials are iron grave markers (figure 1.3a). For example, the marker for Private Webb of the Royal Fusiliers (died 15 December 1899) is located in a corner of the garden away from other memorials. Other memorials are clustered most commonly by regiment. For example, figure 1.3d shows memorials to four soldiers from the Imperial Light Horse (ILH) regiment who were killed at Colenso on 15 December 1899. The three small memorials are for

Troopers and these have the same design and wording, including the ILH motto. The main memorial in the centre is more elaborate, bigger and with the Christian iconography of the cross. Unlike the other memorials, the rank of the soldier is not given and states: “In Loving Memory Of William Henry, son of Rev. J. Longden, of Somerset East C.C.” Another cluster of memorials is shown in figure 1.3e and comprises seven different memorial elements including four iron crosses, each to an “Unknown Soldier of the British Forces”. Larger memorials include a marble stele with a beaded edge for Major J.F.W. Charley of the 27<sup>th</sup> Inniskilling and “erected by his comrades of all ranks”. Other examples of large memorials are also shown in figure 1.3. A granite memorial in the centre of a cluster of memorials is for “John Forbes Whyte, Trooper Bethunes Mounted Infantry” (sic) (figure 1.3b). It includes a biblical quotation (Song of Solomon 2:17) and “Erected by his loving parents” located at the base of the memorial. A concrete cross is located in front of this memorial. A final example is located in a cluster of three large memorials. A marble cross is enveloped by an ivy wreath and surmounted on a stepped plinth. The text reads: “Sacred to the beloved memory of Walter Levinge Thurburn, Capt 2<sup>nd</sup> Royal Fusiliers. Younger son of Charles & Barbara Thurburn, of Kiddington Hall, Oxon”. The lower face of the plinth contains a biblical quotation from Revelation 1:10.

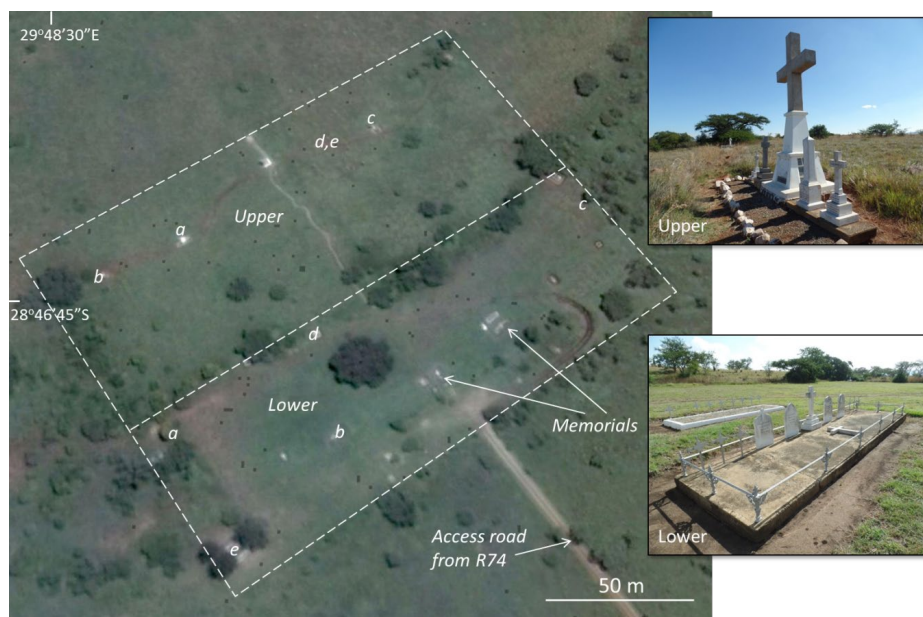


FIGURE 1.2 View of the Clouston Garden of Remembrance, Colenso, showing upper and lower parts of the garden (inset images). Points (a-e) in the lower part mark the memorials shown in figure 1.3. Points (a-e) in the upper part mark the memorials shown in figure 1.4. Background image from Google Earth, image date 31 December 2016.





FIGURE 1.3 Illustration of different memorials at Clouston Garden of Remembrance's lower garden. The positions of memorials (a–e) are marked on figure 1.2.

The upper part of the Garden of Remembrance has a combination of memorials and markers. Markers (e.g. figure 1.4c–d) are obelisks of local igneous rock inset with earlier marble commemoration plaques and commonly mark the positions of engagement on Shooter's Hill (e.g. figure 1.4e). The cluster of memorials, of which the cross shown in figure 1.4a is part, contains several large crosses, some with incomplete memorials, but with combatants from the Natal Carbineers, a regiment of Colonial volunteers loyal to the British crown. The memorial cross in figure 1.4a is for Trooper P.R. (Pete) Adie, “youngest son of J. & E. Adie, Maritzburg” (Pietermaritzburg). Another memorial in this cluster has ‘Pro Patria’ (“For one’s country”) at its base; although evidently intended to refer to Great Britain, this may also be interpreted as the contemporary Boer Republics. A Celtic cross on a stepped plinth with an iron railing surround is shown in figure 1.4b, dedicated to the bacteriologist Captain M.L. Hughes from the Royal Army Medical Corps (RAMC) was killed at Colenso on 15 December 1899. A granite information plaque states: “If it had been possible for him to continue his researches instead of to

serve as a frontline soldier, typhoid vaccine ... might ... have been perfected in time to save the lives of thousands of soldiers and civilians”.



FIGURE 1.4 (a-b) Examples of memorials present at Clouston Garden of Remembrance, upper garden; (c-d) examples of information markers, (e) marble plaque inset within the information marker shown in (d). The positions of memorials (a-e) are marked on figure 1.2.

### *Archaeology and heritage issues today*

During the engagement, Boer trenches were constructed on the north side of the Tugela River, a contemporary photo of which is shown in Bourquin and Torlage.<sup>36</sup> Today, there is little material evidence for these in the landscape, mainly due to ploughing over of these on agricultural land. Removal of many (formerly in situ) markers and memorials to the Clouston Garden of Remembrance can be seen as a strategy to package disparate elements of grave markers, memorial stones, touristic route markers and information plaques, whilst also allowing for freer development within Colenso town. This means that the cemetery site is multipurpose and with the possibility of multiple users and/or viewpoints. There is some evidence, in these different layers of memorialisation,



that different viewpoints have changed over time. Most of the existing memorials at the lower site are of similar age (from around 1910) and show common elements including Christian symbology, text that focuses on sacrifice, loyalty and service to Queen Victoria and the imperial project and with reference to military identity. It is notable that memorials are segregated according to status of the person, with officers located centrally (nearest the entrance to the garden) whereas more modest memorials are used for Privates and these are grouped together by regiment.

In the upper part of the cemetery, information plaques highlight different elements of the narrative of the Colenso engagement and the text of these plaques shows a mix of description of different stages of the engagement and emotive language emphasising valour and sacrifice. For example, an information plaque to Lieutenant Hon F.H.S. Roberts VC, describes: “this gallant gentleman, son of a brave and distinguished soldier”. The reference in several memorials to a soldier’s family or place of origin speaks to wider networks of power and identity. Later, larger memorials paid for by the combatants’ parents show the appropriation of combatants’ identities in order to reflect upon themselves and demonstrate the spatial relationship between Colenso as a site of engagement and social, familial ties drawing the narrative elsewhere. This viewpoint works in both directions, with memorials in the home country/village referring to a fallen son in South Africa.<sup>37</sup> At Clouston Garden of Remembrance, it is notable that local residents, other actors such as Indian stretcher-bearers, Black scouts, etc. and Boer casualties are missing from this narrative.<sup>38</sup> The memorials therefore present a single but layered viewpoint of the engagement at Colenso.

## Spioen Kop

### *Location and engagements*

This site is located on an isolated hilltop 38 kilometres WSW of Ladysmith and thus in the same region as Colenso (figure 1.1). These two sites are connected to each other in time and correspond to the same broad British forces’ advance. Spioen Kop (‘Spy hill’ in Afrikaans) is an isolated hilltop (1 465 metres ASL) set within a wider landscape with other adjacent hilltops (figure 1.5a). The area is today, and was at the time, surrounded by open farmland and with fewer trees than is seen today. Also, today a dam on the Tugela River is located immediately to the south of Spioen Kop. At the time, the dam had not been built and the river ran through this site. Spioen Kop was seen as an important strategic site in the Boer defence line. The engagement at Spioen Kop took place on 23-24 January 1900 and involved a night-time advance of around 1 700 British soldiers up the southwest side of the hill to surprise Boer forces numbering around 195 who

were encamped on the summit. The British forces took the summit early in the morning of 24 January, as the Boer guards retreated and dug a single main trench across the middle part of the flat summit. Later that night, and before sunrise, Boer reinforcements advanced up the northeast slope of the hill, opening fire on British positions. Throughout the day, the Boer forces advanced up to and then across the summit as the battle continued throughout the day, with heavy losses on both sides. The remaining British forces retreated from the hill on the night of 24 January. Pakenham and Torlage describe this battle in detail.<sup>39</sup>

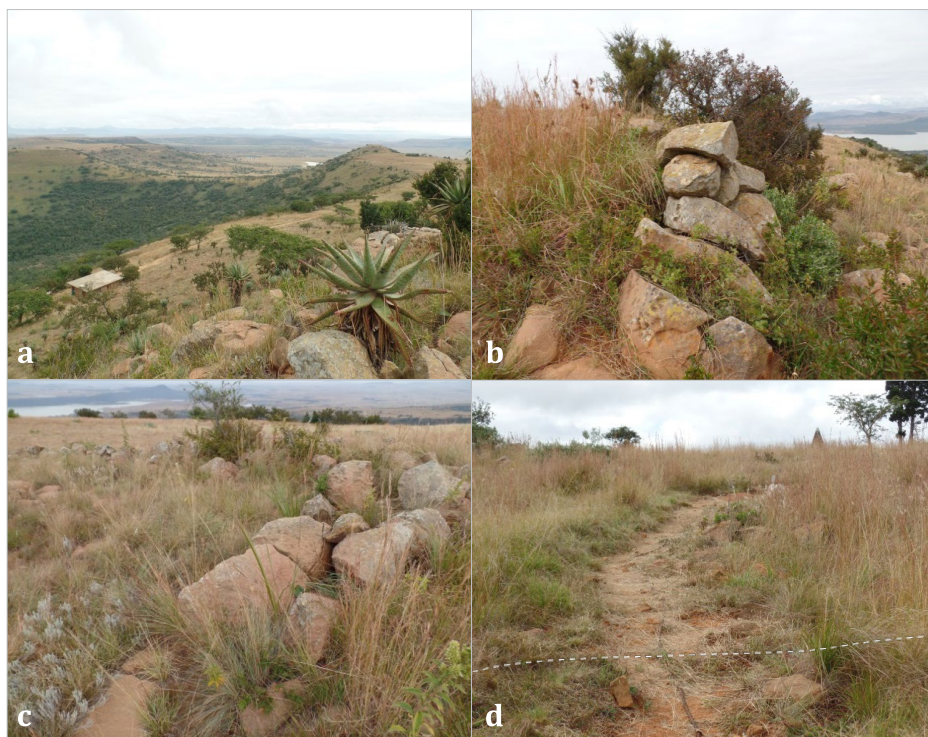


FIGURE 1.5 Different elements of the Spioen Kop landscape. (a) View to the northwest showing adjacent slopes and hilltops; (b) piles of sandstone boulders forming breastwork on the southwest edge of the summit; (c) sandstone boulders forming two wall-like structures, which may reflect re-use of a pre-existing kraal; (d) partly-infilled trench (dotted line), still identifiable in the landscape.

### *Archaeological evidence and memorials today*

The summit of Spioen Kop is relatively flat with steep slopes in particular on the south and west sides. The underlying bedrock is sandstone, which is exposed in many places across the summit and at the summit edge (figure 1.5). Soil is generally quite thin

(<30 centimetres in places) across the summit. This physical geography of the summit region had implications for the tactical use of terrain by combatants. For example, natural rock exposures and loose surface boulders were piled up as breastworks (e.g. figure 1.5b) or used as defensive structures against rifle fire. The example shown in the middle of the summit in figure 1.5c may reflect the re-use of a pre-existing kraal. Likewise, the thin soil was excavated by British troops to form shallow (20-50 centimetres deep) trenches, some of which were partly infilled (figure 1.5d) and subsequently used as mass graves. These modifications to the land surface constitute archaeological features which are still observed in the landscape today.

Different types of memorials are present at Spioen Kop. In the battle, approximately 322 British and 58 Boer soldiers were killed, with around twice these numbers wounded.<sup>40</sup> Most of the British casualties were buried in mass graves within the existing trenches at the site; most of the Boer casualties were removed from the site and buried elsewhere. British memorials and grave markers are most common at the site. Memorials have the same style of construction as at Colenso and include examples dedicated to the Imperial Light Infantry (figure 1.6a) and 1<sup>st</sup> Battalion, South Lancashire Regiment (figure 1.6b). These list casualties from these units by rank and then alphabetically or by commission number. Grave markers and memorials to individual officers are located mainly where these individuals fell. Examples include a granite cross on a pedestal to Major H.H. Massy, Royal Engineers and a marble cross on a stepped plinth to Lieutenant Thomas Flower-Ellis, Thorneycroft's Mounted Infantry. Other large memorials reflect persons of status or power. An example includes: "Lieut. The Hon. Nevill Windsor Hill Trevor (third son of Lord & Lady Trevor), of the T.M.I., late 2<sup>nd</sup> Life Guards". Multiple identities and associations are also demonstrated in these memorials. The most significant grave feature at Spioen Kop is the mass grave for British soldiers. This structure is over 100 metres long and marked by a raised wall with a rubble infill (figure 1.6c). Different memorials (crosses and obelisks) are located around the margins and ends of this structure.

In addition to these memorials for British soldiers, there are other memorials, added to the site in later years, that focus on other groups and through similar acts of remembrance. At the north end of the summit is a memorial marker for Boer soldiers (figure 1.6e). This was erected in 1940 and bears an Afrikaans inscription translated as: "Brave and dutiful to people and homeland". Boer soldiers names are arranged by area of origin (Krugersdorp, Lydenburg, Pretoria, etc.). There is also a granite obelisk memorial (constructed in 2015) to Indian and Black personnel who were involved at Spioen Kop as scouts, messengers, riders, cooks, stretcher-bearers and other auxiliary services, for both the British and Boer sides (figure 1.6f).





FIGURE 1.6 Examples of memorials at Spioen Kop. (a) Pedestal memorial for soldiers of the Imperial Light Infantry; (b) memorial for soldiers of the 1<sup>st</sup> Battalion South Lancashire Regiment; (c) viewpoint of British mass grave; (d) Iron cross memorial. The accompanying plaque reads: 'In memory of unknown Burger sentry killed on this spot 24<sup>th</sup> January 1900'. An equivalent statement in Afrikaans is also on the plaque and (e) memorial to Boer combatants (built 1940); (f) memorial to Indian and Black personnel (built 2015).

### *Archaeology and heritage issues today*

Spioen Kop as a site is run by Heritage KwaZulu-Natal and there is infrastructure paid for by the UK Ministry of Defence including a gatehouse and access road to support this tourist activity. An information board is provided in English, Afrikaans and isiZulu. Both UK and South African flags fly at the site entrance. Spioen Kop is a well-known and well-used heritage site today. There is a trail around the hilltop with numbered markers and an accompanying tourist leaflet that describes key stages in the battle. The site is also managed, in part, by the South African Military History Society/Die Suid-Afrikaanse Krygshistoriese Vereniging. Physical archaeological evidence is still present at Spioen Kop in the form of trenches and breastworks. Memorials, graves and other heritage features are both well marked and well visited. The style, imagery and text of these memorials are generally quite similar to and of broadly the same age [1910s] as, Colenso sites and commemorate British soldiers only. The size, number and different styles of British memorials at Spioen Kop attest to its importance as a site. Similar issues of heritage and identity are present here as at Colenso. These include reference to the area from which combatants came and their familial connections. The largest memorial at the site, located at the head of the British mass graves, is an obelisk on a six-sided pedestal and stepped plinth, each side of which contains a large marble plaque with names of casualties from different regiments, arranged by rank. The inscription on the plinth lists the military units who erected the monument.

These different narratives demonstrate different associations of combatants with the wider world and can be considered as expressions of power in the memorial landscape: the large obelisk physically dominates and acts as a marker in the landscape. By contrast, the Boer memorial is located at the north of the site and overlooks the agricultural regions of the Free State and KwaZulu-Natal, from which many of its combatants came. The different arrangement of combatants on British (by rank) and Boer (by region) memorials is of note. The British memorials promulgate ideas of power and status with respect to rank and family, but also with reference to sacrifice to Queen and God. Power is hierarchical. The Boer memorial does not list ranks and their geographical grouping demonstrates that these were ordinary men from rural communities, not professional soldiers, that were united as comrades to defend “people and homeland”. This memorial therefore illustrates a different viewpoint of identity through commemoration.

## Discussion

Although arising from the same conflict and commemorated afterwards at around the same time, the sites of Colenso and Spioen Kop show very different types and styles of archaeological, heritage and memorialisation evidence. At Colenso, the only extant archaeological evidence is possibly some gun battery emplacements; Boer trenches north of the Tugela on the adjacent floodplain are mainly ploughed out, although LiDAR could be used as a tool to better map these features. At Spioen Kop, trenches and breastworks are still in existence on the summit itself and it may be that Boer trenches in lowland areas north of the summit can still be identified. Although both sites contain many British graves, memorials and markers, these are located at different places in the landscape and for different reasons. For example, at the Clouston Garden of Remembrance, some memorials are grouped by regiment (e.g. figure 1.2) whereas others are grouped by status (rank) of the individual. In the upper garden at Colenso and at Spioen Kop, some memorials are located where combatants were killed or injured. Other memorials at Spioen Kop face the British mass graves.

The memorialisation practiced at Colenso and Spioen Kop demonstrates a shift towards a more public display of grief and open commemoration of public events that took place during the late 19<sup>th</sup>/early 20<sup>th</sup> centuries in Great Britain.<sup>41</sup> This was driven in part by a richer middle class, reportage of world events in newspapers and magazines and greater literacy. These factors facilitated greater public debate of current events and *fin de siècle* shifts in relationships between the general public and institutions such as the monarchy, empire, church, state and army. Such public displays of remembrance developed after First World War and persist within complex military/political spaces today.<sup>42</sup> At Colenso and Spioen Kop, the mere physical presence of memorials can be seen as an act of ownership, in which both the space and the memory are claimed.<sup>43</sup> However, another important theme in memorialisation is absence, in which the things that are missing are as relevant as those that are present.<sup>44</sup> One panel of the Indian memorial at Spioen Kop speaks of: “those whose names are lost to history” (figure 1.6f). At Colenso, an anonymous grave marker plaque stating: “Here lies a brave British soldier” is located between other graves for a Lieutenant Colonel and a Captain. The juxtaposition of these three dead soldiers is clear. The more recent development of new memorials at Spioen Kop can be seen as a strategy to give voice to the forgotten, what Landzelius calls the ‘dis(re)membred’.<sup>45</sup> However, some recent studies view ‘dis(re)membering’ through memorialisation as a political and ethical act<sup>46</sup> and thus these studies caution against memorialisation as a way to atone for past neglect.<sup>47</sup>

Battlefield sites of the past can be more commonly viewed as cultural, heritage or memorial landscapes.<sup>48</sup> The advantage of such an approach is that individual sites can be put into a wider context, especially where the actions and outcomes of military engagements such as of the Anglo-Boer War were strongly influenced by topography, rivers and weather.<sup>49</sup> This idea has been most commonly developed at USA Civil War sites.<sup>50</sup> Cultural landscapes by definition reflect the interplay of both environmental and human factors and have particular resonance in South Africa where multiple and parallel cultural identities and values exist.<sup>51</sup> The nature of memorialisation within such landscapes poses different issues, however, based not so much on identifying the deceased on grave markers and plaques, but on representation of statues and other iconography and imagery.<sup>52</sup> It is notable that at Colenso and Spioen Kop themselves, these representations are absent, but the iconography is very strong at the Anglo-Boer War Museum in Bloemfontein, Free State, with numerous statues and sculptures, the National Women's Memorial [1913], Concentration Camps Memorial [2010], the wall commemorating Burgher deaths on Commando [2012] and a Garden of Remembrance [2015]. Thus, battlefield sites as cultural landscapes may or may not contain iconographies of 'culture' or manifestations of cultural identity, whereas memory and identity may be reserved for specific spaces where rituals of mourning (laying of flowers, wreaths, prayers) can take place.<sup>53</sup> It is notable that cultural landscapes themselves commonly lie outside of these formal spaces (contrast the lower and upper gardens at Clouston).

## Conclusions and a Future Research Agenda

The Anglo-Boer War is one of several conflicts between different cultures and beliefs that have shaped the recent history and heritage of South Africa.<sup>54</sup> The social, political and military repercussions of the conflict were felt beyond its borders, not least in Great Britain which was forced to reflect on its most challenging and costly military campaign fought over the hundred years prior to First World War.<sup>55</sup> In particular, the experience of combat in an environment that merged modern weaponry (including magazine-fed rifles with smokeless ammunition, machine guns and high-explosive artillery shells) and the unusually clear atmospheric conditions and long fields of view conferred high casualty rates on the battlefield and at longer ranges than previously experienced.<sup>56</sup> A corollary of these battlefield conditions was the widespread use of temporary field fortifications, trenches and stone breastworks.<sup>57</sup> The conflict can therefore be placed in the evolution of military practice that reflects the escalating power of small arms and artillery over the past two centuries and anticipates the tactical advantages of defensive positions that were to become the hallmark of First World War.<sup>58</sup> Anglo-Boer War battlefields and the wider array of conflict landscapes can also be viewed as important

elements in framing the country's history and collective identity and also for the role of heritage tourism in economic development in rural areas.<sup>59</sup> Conflict archaeological research also has benefits for public outreach and community engagement.<sup>60</sup>

Three aspects of battlefield landscapes that present particular research potential in Anglo-Boer War contexts are identified:

1. Surveying extant field fortifications, especially with airborne LiDAR,<sup>61</sup> can be used to map and analyse force dispositions and battle narratives. Surface features may have low preservation potential in areas that have experienced urban expansion or agricultural use (e.g. at Colenso). Elsewhere and especially in rocky hills and ridges, extant field fortifications testify to the tactical advantages conferred by high ground.<sup>62</sup> Indeed, over half of the 43 Anglo-Boer War battle and skirmish sites identified by Passmore et al. are associated with hilltops and ridges.<sup>63</sup> Three-dimensional visualisation of landscapes and archaeological sites is increasingly used for public engagement.
2. The recovery and mapping of surface and near-surface artefacts from small arms (especially rifle cartridge cases) is increasingly used in archaeological surveys and can yield information on the disposition and movements of combatants.<sup>64</sup> This is generally lacking in Anglo-Boer War studies, although well-preserved cartridge cases have been reported from isolated sites.<sup>65</sup> These artefacts appear to have been redeposited and hence were not diagnostic of their original battlefield context, but they do point to the prospect for undisturbed examples on battlefield sites elsewhere.
3. In South Africa, although sites have statutory recognition, site management and conservation is not enacted uniformly at the provincial level through the South African Heritage Resources Agency. Thus, in the context of the increasing recognition of battle sites as cultural landscapes, a fuller national-scale audit of sites and monuments is needed.

## ENDNOTES AND REFERENCES

1. Geier, C.R.; Scott, D.D. & Babits, L.E (eds.). 2014. *From These Honored Dead: Historical Archaeology of the American Civil War*. Gainesville: University Press of Florida.  
<https://doi.org/10.5744/florida/9780813049441.001.0001>
2. Saunders, N.J. 2007. *Killing time: Archaeology and the First World War*. Stroud: Sutton.;  
Robertshaw, A. & Kenyon, D. 2008. *Digging the Trenches: the archaeology of the Western Front*. Barnsley: Pen & Sword Military.
3. Dobinson, C.S.; Lake, J. & Schofield, A.J. 1997. Monuments of war: defining England's 20<sup>th</sup> century defence heritage. *Antiquity*, 71:288-299. <https://doi.org/10.1017/S0003598X0008491X>  
Passmore, D.G.; Harrison, S. & Capps Tunwell, D. 2014. Second World War conflict archaeology in the forests of north-west Europe. *Antiquity*, 88:1275-1290.  
<https://doi.org/10.1017/S0003598X00115455>



4. Pollard, T. 2009. Seven Eventful Days in Paraguay: Reconnoitering the Archaeology of the War of the Triple Alliance. In: D.D. Scott, L.E. Babits & C. Haecker (eds.), *Battlefield Archaeology from the Roman Empire to the Korean War*. Washington, D.C.: Potomac Books. pp. 314-335.
5. Johnson, D.M. 2009. Apache Victory against the U.S. Dragoons, the Battle of Cieneguilla, New Mexico. In: D.D. Scott, L.E. Babits & C. Haecker (eds.), *Battlefield Archaeology from the Roman Empire to the Korean War*. Washington, D.C.: Potomac Books. pp. 235-254;  
Laumbach, K.W. 2009. Buffalo Soldiers versus the Apache: The Battle in Hembrillo Basin, New Mexico. In: D.D. Scott, L.E. Babits & C. Haecker (eds.), *Battlefield Archaeology from the Roman Empire to the Korean War*. Washington, D.C.: Potomac Books. pp. 336-358.
6. Carlson-Drexler, C.G. 2008. Monuments and memory at San Juan Hill: Archaeology of the Spanish-Cuban-American War. *The SAA Archaeological Record*, 8(1):26-28.
7. Banks, I. 2007. Ghosts in the Desert: the Archaeological Investigation of a Sub-Saharan Battlefield. *Journal of Conflict Archaeology*, 3(1):1-28. <https://doi.org/10.1080/15740773.2018.1551981>
8. Homann, A. & Weise J. 2009. The Archaeological Investigation of Two Battles and an Engagement in North Germany from the 19<sup>th</sup> Century: A Summary of Work Carried Out at Idstedt, Grossbeeren and Lauenburg. *Journal of Conflict Archaeology*, 5(1):27-56.  
<https://doi.org/10.1163/157407709X12634580640218>
9. Pollard, T. 2002. The Mountain is their Monument: An Archaeological Approach to the Landscapes of the Anglo-Zulu War of 1879. In: P. Doyle & M.R. Bennett (eds.), *Fields of Battle. Terrain in Military History*. Dordrecht: Springer. pp. 117-135. [https://doi.org/10.1007/978-94-017-1550-8\\_8](https://doi.org/10.1007/978-94-017-1550-8_8)  
Pollard, T.; Banks, I.; Arthur, J.; Clark, J. & Oliver, N. 2005. Survey and Excavation of the Anglo-Zulu War Fort at Eshowe, KwaZulu-Natal, South Africa. *Journal of Conflict Archaeology*, 1(1):133-180.  
<https://doi.org/10.1163/157407705774929015>  
Gilbin, J.W. 2015. Towards an archaeology of recent conflict in western Great Lakes Africa. *Journal of Conflict Archaeology*, 10(2):123-146. <https://doi.org/10.1179/1574077315Z.000000000048>
10. Schofield, J.; Johnson, W.G. & Beck, C.M (eds.). 2002. *Matériel Culture: The archaeology of 20<sup>th</sup> century conflict*. London: Routledge;  
Saunders, N.J. 2012. *Beyond the dead horizon: Studies in modern conflict archaeology*. Oxford: Oxbow Books.
11. Wessels, A. 2011. Boer Guerrilla and British Counter-Guerrilla Operations in South Africa, 1899-1902. *Scientia Militaria – South African Journal of Military Studies*, 39(2):1-24.  
<https://doi.org/10.5787/39-2-110>
12. Everdell, W.R. 1997. *The First Moderns: Profiles in the Origins of 20<sup>th</sup> Century Thought*. Chicago: University of Chicago Press. <https://doi.org/10.7208/chicago/9780226224848.001.0001>  
Moshenska, G. & Myers, A. 2011. An Introduction to Archaeologies of Internment. In A. Myers & G. Moshenska (eds.), *Archaeologies of Internment*. New York: Springer. pp. 1-20.  
[https://doi.org/10.1007/978-1-4419-9666-4\\_1](https://doi.org/10.1007/978-1-4419-9666-4_1)
13. For examples of historical works see: Pakenham, T. 1979. *The Boer War*. London: Weidenfeld and Nicholson;  
Porter, A. 2000. The South African War and the Historians. *African Affairs*, 99:633-648.  
<https://doi.org/10.1093/afraf/99.397.633>  
Van der Waag, I. 2002. Re-fighting the Second Anglo-Boer War: Historians in the Trenches. *Journal for Contemporary History*, 27(2):184-210.;

- Judd, D. & Surridge, K. 2013. *The Boer War: A History*. London: IB Tauris & Co.;
- For examples of social science works see: Cuthbertson, G.; Grundlingh, A. & Suttie, M.L (eds.). 2002. *Writing a wider war: rethinking gender, race, and identity in the South African War, 1899-1902*. Cape Town: David Philip Publishers.;
- Stanley, L. & Dampier, H. 2005. Aftermaths: post/memory, commemoration and the concentration camps of the South African War 1899-1902. *European Review of History: Revue européenne d'histoire*, 12(1):91-119.;
- Van Heyningen, E. 2010. A tool for modernisation? The Boer concentration camps of the South African War, 1900-1902. *South African Journal of Science*, 106(5-6).  
<https://doi.org/10.4102/sajs.v106i5/6.242>
14. Passmore, D.G.; Knight, J. & Harrison, S. 2015. Military Geography: Landscapes of the Anglo-Boer War. In: S. Grab & J. Knight (eds.), *Landscapes and Landforms of South Africa*. Cham: Springer-Verlag. pp. 155-165. [https://doi.org/10.1007/978-3-319-03560-4\\_18](https://doi.org/10.1007/978-3-319-03560-4_18)
15. Van Vollenhoven, A.C. 1994. An Historical Archaeological Investigation of Fort Daspoortrand, Pretoria. *South African Field Archaeology*, 3:49-54.
16. Van Vollenhoven, A.C.; Pelser, A.J. & Van den Bos, J.W. 1998. A historial-archaeological investigation of an Anglo-Boer War British outpost in the Kruger National Park. *Koedoe*, 41(2):113-120.  
<https://doi.org/10.4102/koedoe.v41i2.256>
- Badenhorst, S.; Plug I.; Pelser, A.J. & Van Vollenhoven, A.C. 2002. Faunal analysis from Steinaecker's Horse, the northernmost British military outpost in the Kruger National Park during the South African War. *Annals of the Transvaal Museum*, 39:57-63.
17. Huffman, T.N. 2012. Historical archaeology of the Mapungubwe area: Boer, Birwa, Sotho-Tswana and Machete. *Southern African Humanities*, 24:33-59.
18. Badenhorst, S. 2002. Explaining the past through history and archaeology: a case study of three sites in Irene, Centurion (South Africa). In: J.A. van Schalkwyk (ed.), *Research by the National Cultural History Museum*. Pretoria: National Cultural History Museum. 78-87.
19. Forssman, T. & Louw, C. 2016. Leaving a Mark: South African War-Period (1899-1902) Refuge Graffiti at Telperion Shelter in Western Mpumalanga, South Africa. *South African Archaeological Bulletin*, 71:4-13.
20. Dreyer, J. 2001. Archaeology and the Anglo-Boer War (1899-1902): a report on the discovery of the black refugee camp and cemetery at Brandfort, Free State. *South African Journal of Ethnology*, 24(4):131-137.
21. Nienaber, W.C. & Steyn, M. 1999. Exhumation and analysis of the remains of a black native participant in the Anglo-Boer War (1899-1902), KwaZulu-Natal. *South African Journal of Cultural History*, 13(2):94-110.
22. Blades, B.S. 2003. European Military Sites as Ideological Landscapes. *Historical Archaeology*, 37(3):46-54. <https://doi.org/10.1007/BF03376610>
- Cerarols Ramírez, R. 2009. Landscape and memory: literary recreations of the military colonial geography in Morocco. *Boletín de la A.G.E.*, 51:415-417.
23. These sites are described and listed in Passmore, D.G.; Knight, J. & Harrison, S. 2015. Military Geography: Landscapes of the Anglo-Boer War. In: S. Grab & J. Knight (eds.), *Landscapes and Landforms of South Africa*. Cham: Springer-Verlag. pp. 155-165.  
<https://doi.org/10.1007/978-3-319-03560-4>

24. Ibid.
25. Hall, D. 1999. *The Hall Handbook of the Anglo-Boer War, 1899-1902*. Pietermaritzburg: University of Natal Press.
26. Pakenham, 1979, op. cit.
27. See for example: Ryan, C (ed.). 2007. *Battlefield Tourism: History, Place and Interpretation*. Oxford: Elsevier;  
Gegner, M. & Ziino, B (eds.). 2012. *The Heritage of War*. Oxford: Routledge.  
<https://doi.org/10.1179/204243410X12674422128830>
28. See for example: Dominy, G. & Callinicos, L. 1999. "Is there anything to celebrate?" Paradoxes of policy: An Examination of the State's Approach to Commemorating South Africa's Most Ambiguous Struggle. *South African Historical Journal*, 41(1):388-403.  
<https://doi.org/10.1080/02582479908671900>  
Grundlingh, A. 2004. Reframing Remembrance: the Politics of the Centenary Commemoration of the South African War of 1899-1902, *Journal of South African Studies*, 30(2):359-375.  
<https://doi.org/10.1080/0305707042000215400>
29. Passmore et al., 2015, op. cit.
30. See, for example, Blades, 2003, op. cit.;  
Cerarols Ramirez, 2009, op. cit.;  
Gheyle, W.; Dossche, R.; Bourgeois, J.; Stichelbaut, B. & Van Eetvelde, V. 2014. Integrating Archaeology and Landscape Analysis for the Cultural Heritage Management of a First World War Militarised Landscape: The German Field Defences in Antwerp. *Landscape Research*, 39(5):502-522.  
<https://doi.org/10.1080/01426397.2012.754854>;  
Stephens, J.R. 2014. Commemorative Landscapes to the Missing: The HMAS Sydney II Memorial. *Landscape Research*, 39(5):523-541. <https://doi.org/10.1080/01426397.2012.756862>
31. Cooke, S. 2000. Negotiating memory and identity: the Hyde Park Holocaust Memorial, London. *Journal of Historical Geography*, 26(3):449-465. <https://doi.org/10.1006/jhge.2000.0238>  
Kalinowska, M. 2012. Monuments of memory: defensive mechanisms of the collective psyche and their manifestation in the memorialization process. *Journal of Analytical Psychology*, 57:425-444.  
<https://doi.org/10.1111/j.1468-5922.2012.01984.x>
32. Hall, 1999, op. cit., pp. 202-203.
33. Venter, D. 2011. Battlefield tourism in the South African context. *African Journal of Hospitality, Tourism and Leisure*, 1(3):1-5;  
Van der Merwe, C.D. 2014. Battlefields Tourism: The status of heritage tourism in Dundee, South Africa. *Bulletin of Geography, Socio-economic Series*, 26:121-139.  
<https://doi.org/10.2478/bog-2014-0049>
34. See for example: Gallardo, J.H. & Stein, T.V. 2007. Participation, power and racial representation: Negotiating nature-based and heritage tourism development in the rural south. *Society and Natural Resources*, 20(7):597-611. <https://doi.org/10.1080/08941920701216545>  
Marschall, S. 2013. Woza eNanda: perceptions of and attitudes towards heritage and tourism in a South African township. *Transformation*, 83:32-55. <https://doi.org/10.1353/trn.2013.0032>
35. Bourquin, S.B. & Torlage G. 1999. *The Battle of Colenso*. Randburg: Ravan Press.
36. Ibid.

37. Connelly, M. & Donaldson, P. 2010. South African War (1899-1902) memorials in Britain: A case study of memorialization in London and Kent. *War & Society*, 29(1):20-46.  
<https://doi.org/10.1179/204243410X12674422128830>
38. See Hall, 1999, op. cit.
39. Pakenham, 1979, op. cit.;  
Torlage, G. 1999. *The Battle of Spioenkop*. Randburg: Ravan Press.
40. Ibid.
41. Connelly & Donaldson, 2010, op. cit.
42. Jenkins, K.N.; Megoran, N.; Woodward, R. & Bos, D. Wootton Bassett and the political spaces of remembrance and mourning. *Area*, 44(3):356-363. <https://doi.org/10.1111/j.1475-4762.2012.01106.x>
43. Marschall, S. 2006. Visualizing memories: the Hector Pieterse memorial in Soweto. *Visual Anthropology*, 19:145-169. <https://doi.org/10.1080/08949460600598695>  
Marschall, S. 2008. Ncome-monument and museum as "critical response". *Museum Anthropology Review*, 2:88-114.
44. Gough, P. 2004. Sites in the imagination: the Beaumont Hamel Newfoundland Memorial on the Somme. *Cultural Geographies*, 11:235-258. <https://doi.org/10.1191/1474474003eu306oa>  
Maddrell, A. 2013. Living with the deceased: absence, presence and absence-presence. *Cultural Geographies* 20(4):501-522. <https://doi.org/10.1177/1474474013482806>
45. Landzelius, M. 2003. Commemorative dis(re)membering: erasing heritage, spatializing disinheritance. *Environment and Planning D: Society and Space*, 21:195-221.  
<https://doi.org/10.1068/d286t>
46. See Jenkins et al., 2012, op. cit.;  
Marschall, S. 2013. Woza eNanda: perceptions of and attitudes towards heritage and tourism in a South African township. *Transformation*, 83:32-55. <https://doi.org/10.1353/trn.2013.0032>  
Till K.E. & Kuusisto-Arponen, A.-K. 2015. Towards responsible geographies of memory: Complexities of place and the ethics of remembering. *Erdkunde*, 69(4):291-306.  
<https://doi.org/10.3112/erdkunde.2015.04.01>
47. Marschall, 2008, op. cit.;  
Esterhuysen, A.; Knight, J. & Keartland, T. 2018. Mine waste: The unseen dead in a mining landscape. *Progress in Physical Geography*, 42(5):650-666.  
<https://doi.org/10.1177/0309133318793581>
48. Blades, 2003, op. cit.
49. Passmore et al., 2015, op. cit.
50. See for example: Hippensteel. S.G. 2008. Reconstruction of a Civil War Landscape: Little Folly Island, South Carolina. *Geoarchaeology: An International Journal*, 23(6):824-841.;  
Hurt, D.A. 2010. Reinterpreting the Washita Battlefield National Historic Site. *The Geographical Review*, 100(3):375-393. <https://doi.org/10.1111/j.1931-0846.2010.00042.x>
51. Marschall, 2008; 2013; op. cit.
52. Marschall, 2006, op. cit.
53. Jenkins et al., 2012, op. cit.;  
Kalinowska, 2012, op. cit.

54. Cuthbertson, G. & Jeeves, A. 1999. The many-sided struggle for Southern Africa, 1899-1902. *South African Historical Journal*, 41(1):2-21.;  
Grobler, J. 2008. The Impact of Politics on Heritage and Cultural Tourism in South Africa. *S.A. Tydskrif vir Kultuurgeskiedenis*, 22(1):163-185. <https://doi.org/10.1080/02582479908671881>
55. Porter, A. 2000. The South African War and the Historians. *African Affairs*, 99:633-648.;  
Badsey, S. 2007. The Boer War (1899-1902) and British Cavalry Doctrine: A Re-Evaluation. *The Journal of Military History*, 71(1):75-97. <https://doi.org/10.1353/jmh.2007.0001>
56. See for example: Jones, S. 2014. "Shooting Power": A Study of the Effectiveness of Boer and British Rifle Fire, 1899-1914. *British Journal for Military History*, 1(1):29-47.;  
Jones, S. 2016. "The Shooting of the Boers was Extraordinary": British Views of Boer Marksmanship in the Second Anglo-Boer War, 1899-1902. In: K. Jones, G. Macola & D. Welch (eds.), *A Cultural History of Firearms in the Age of Empire*. Oxford: Routledge. pp. 251-266.
57. Pakenham, 1979, op. cit.
58. See for example: Pollard, T. 2014. Fortifications, Archaeology of. In: C. Smith (ed.), *Encyclopedia of Global Archaeology*. New York: Springer. pp. 2851-2863.  
[https://doi.org/10.1007/978-1-4419-0465-2\\_1367](https://doi.org/10.1007/978-1-4419-0465-2_1367)
59. See for example: Moeller, M. 2011. *Battlefield Tourism in South Africa with Special Reference to Isandlwana and Rorke's Drift, KwaZulu-Natal*. MPhil dissertation, University of Pretoria, South Africa.;  
Venter, 2011, op. cit.;  
Van der Merwe, 2014, op. cit.
60. Banks, I.; Koskinen-Koivisto, E. & Seitsonen, O. 2017. Public engagements with Lapland's Dark Heritage: Community archaeology in Finnish Lapland. *Journal of Community Archaeology & Heritage* in press. <https://doi.org/10.1080/20518196.2017.1383672>
61. Opitz, R.S. & Cowley, D.C (eds.). 2013. *Interpreting archaeological topography: Airborne Laser Scanning, 3D Data and Ground Observation*. Oxford: Oxbow Books.
62. Huffman, 2012, op. cit.
63. Passmore et al., 2015, op. cit.
64. See for example: Scott, D.D. & McFeaters, A.P. 2011. The archaeology of historic battlefields: A history and theoretical development in conflict archaeology. *Journal of Archaeological Research*, 19(1):103-132. <https://doi.org/10.1007/s10814-010-9044-8>
65. Dreyer, J. 1994. Cartridges and Chronology: an Exercise in Relative Dating. *South African Field Archaeology*, 3:44-48.;  
Badenhorst, 2012, op. cit.

# Battlefield Tourism at Magersfontein

THE CASE OF HERITAGE TOURISM IN THE  
NORTHERN CAPE, SOUTH AFRICA

2

Clinton van der Merwe



## Introduction

Within international tourism, heritage tourism is an expanding and significant sector within the global tourism economy.<sup>1</sup> Indeed, it has been argued that “heritage is (or should be) regarded as one of the most significant and fastest growing components of tourism” in the world.<sup>2</sup> In South Africa, the geography of tourism is an important issue of scholarly interest and investigation with various studies having calculated that tourism currently contributes about R184,4 billion (7,9%) of the Gross Domestic Product (GDP) in South Africa.<sup>3</sup> Tourism in South Africa directly employs about 919 000 people, or approximately 7% of the country’s workforce.<sup>4</sup> Policy makers in South Africa identify heritage tourism as a niche of cultural tourism and recognise it as a sustainable avenue to expand the future tourism economy.<sup>5</sup> For local policy-makers, the value of heritage tourism is particularly appreciated in economically weak or marginal areas of the country where it can be a vehicle for energising tourism-led local development.<sup>6</sup>



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According to Light, heritage tourism is not a recent phenomenon. He argues that the earliest “examples of this activity can be identified in the visits made by affluent Romans to the ruins of ancient Greece”.<sup>7</sup> Many heritage tourism scholars increasingly refer, however, to this form of cultural tourism as a “new market niche”.<sup>8</sup> South Africa is a relatively recent entrant within the international heritage tourism economy and is therefore described by McCamley and Gilmore as one of its “emerging heritage regions”.<sup>9</sup> In South Africa, there is growing recognition of the potential for developing the country’s heritage tourism economy.<sup>10</sup> As far back as the mid-1990s the Department of Environmental Affairs and Tourism (DEAT) acknowledged the potential for tourism in South Africa’s development.<sup>11</sup> In particular, the Department of Arts and Culture (DAC) recognised the importance of heritage for national economic development promotion.<sup>12</sup> Only recently, however, has the specific potential of heritage tourism been acknowledged as meeting the goals of the 2011 National Tourism Sector Strategy.<sup>13</sup>

Arguably, critical recognition of the national importance of heritage tourism for South Africa is evidenced most clearly by the preparation and launch, in 2013, by the National Department of Tourism (NDT) of its *National Heritage and Cultural Tourism Strategy (NHCTS)*.<sup>14</sup> In the NHCTS, it is stated that the country wishes “to realise the global competitiveness of the South African heritage and cultural resources through product development for sustainable tourism and economic development”.<sup>15</sup> The central objective of this strategy is to give strategic direction for the development and promotion of heritage and cultural tourism in South Africa and to furnish a framework for the coordination and integration of heritage and culture into mainstream tourism. Although strong policy support for cultural and heritage tourism is in place, so far there has been only limited academic work in the field of heritage and cultural tourism in South Africa, as well as the wider region of Southern Africa.<sup>16</sup> More especially, the evidence base is limited concerning the country’s heritage assets and geography, as well as the organisation and local development impacts of heritage tourism in South Africa.<sup>17</sup>

Furthermore, the challenges facing heritage tourism to maximise the benefits for local communities are not well understood, yet represent a critical issue for both national and local policy-makers. It is against this backdrop that this chapter sought to address a number of knowledge gaps surrounding heritage tourism in South Africa. The central objective of this chapter is to examine the definition of heritage tourism in South Africa in terms of battlefield tourism and to examine the local development impacts and challenges for local development of heritage tourism, at Magersfontein (in the Northern Cape) in South Africa.

The overarching theoretical framework used is that of ‘niche tourism’ – of which heritage tourism is a part, both in the developed and developing worlds. The core research problem was to determine how South Africa could maximise the local development potential of heritage tourism.<sup>18</sup> This issue is situated within the international scholarship on heritage tourism, which includes several examples of the immediate and local benefits of heritage tourism impacts on the local economy.<sup>19</sup> It is argued in this chapter that, based upon the international experience of battlefield tourism, the challenges facing the development of battlefield tourism in South Africa need to be addressed in order for it to maximise its impacts for local tourism economies and, more broadly, for local economic development. This chapter investigates what is required for the Battlefields in South Africa to become a sustainable and responsible form of heritage tourism through a case study approach – using the Battle of Magersfontein (see figure 2.1). A previous study sought to investigate the motivations of tourists visiting battlefield sites as part of heritage tourism in South Africa.<sup>20</sup> Arguably, if South Africa is to more effectively market and sustain heritage tourism, extended research on battlefield tourism and tourists is necessary. Several previous studies in heritage tourism in South Africa have demonstrated the value of an understanding of who heritage tourists are in order to better interpret this market of cultural or heritage tourism.<sup>21</sup>

In terms of the organisation of the discussion, the local case study of the battlefield at Magersfontein Museum is first situated within the international context of research on heritage and battlefield tourism. The position of the battlefield in local tourism development policies is examined and the challenges facing the maximisation of local impacts of the battlefield tourism is explored. The chapter draws from a number of different sources. These include planning documents of the local municipalities in the area; documentary sources were collated and analysed to ascertain the local promotion initiatives around tourism in the Northern Cape (and the surrounding locales). Use was made of the IHS Global Insight<sup>22</sup> national tourism databases to examine local-level data on trends in tourism trips, estimates of tourism spending and of tourism spending to local GDP within the local municipalities of the battlefield concerned. Data was extracted for trends in tourism in the local municipality of Sol Plaatje for the period 2001-2015. Field research was undertaken to profile and characterise visitors to the battlefield in 2014-2015 to understand local heritage tourism and to explore tourist perceptions of heritage and heritage tourism. The latter, it is suggested, is essential so as to enable local decision-makers within the tourism industry to more effectively segment-market and grow the ‘battlefields tourism economy’.<sup>23</sup>



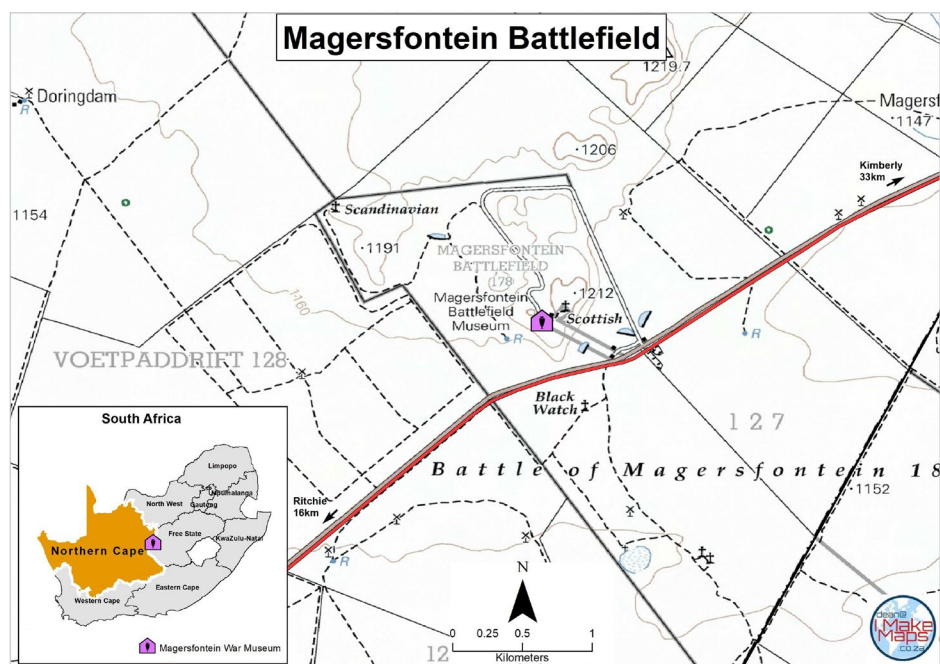


FIGURE 2.1 The Location of Magersfontein Battlefield Et Museum in the Northern Cape  
Source: Author's Map

## What is Heritage Tourism?

Heritage tourism has become increasingly popular over time and is well established in many countries around the world, often being associated as a large segment of many older and historically significant countries across the globe.<sup>24</sup> Throughout the global North, heritage tourism is a large component of the national GDP for many developed countries, which have tapped into and successfully marketed their rich history and heritage as part of their tourism appeal.<sup>25</sup> Johnson draws attention to the fact that there “has been a huge expansion in the number of heritage sites over the past 30 years, coinciding with the expansion of tourism activity worldwide”.<sup>26</sup> Heritage tourism is also growing in popularity and appeal in the global South.<sup>27</sup> Using the United Nations World Tourism Organisation (UNWTO) data, Orbasli and Woodward argued that cultural tourism (of which heritage tourism forms a substantial part) represents between 35 and 40% of all global tourism, recording approximately three times the rate of growth of global tourism as a whole.<sup>28</sup>

Light argues that on a global scale, heritage tourism continues to expand with both the demand and supply side of the industry growing.<sup>29</sup> He draws attention to new forms of

heritage tourism, for example, that have emerged based on the legacy of communism in central and eastern Europe, the heritage of colonialism and the making of new post-colonial interpretations of national history and of heritage sites linked to the struggle against apartheid in South Africa.<sup>30</sup> Overall, it has been argued by one international observer, that heritage tourism “is today one of the most significant forms of special interest tourism around the globe”.<sup>31</sup> Heritage is a contested idea and forms part of various disciplines and academic endeavours.<sup>32</sup> For one observer, heritage is considered “as the contemporary process through which human societies engage with and make use of, their pasts”.<sup>33</sup> Waterton and Watson offer heritage as “a version of the past received through objects and display, representations and engagements, spectacular locations and events, memories and commemorations and the preparation of places for cultural purposes and consumption”.<sup>34</sup> In tourism, Waterton and Watson argue that “heritage objects came to represent an authorised version of the past in places and spaces that were prepared for visitors”.<sup>35</sup> This said, whilst the terms *heritage* and *tourism* have been described as ‘strange bedfellows’, it is argued that “there is increasing evidence of their coupling around the globe”.<sup>36</sup>

Many heritage tourism scholars increasingly refer to this form of cultural tourism as a “new market niche” of tourism and contrast it with mass tourism.<sup>37</sup> It has been argued that niche tourism “can be considered to be an alternative, almost antithesis to modern mass tourism ... Niche tourism can, therefore, be defined as catering to the needs of specific markets by focussing on more diverse tourism products”.<sup>38</sup> Several definitions have been put forward to define heritage tourism. In one of the most widely acknowledged definitions, Timothy and Nyaupane define heritage tourism as that which:

relies on living and built elements of culture and folkways of today, for they too are inheritances from the past; other immaterial heritage elements, such as music, dance, language, religion, foodways and cuisine, artistic traditions, and festivals; and material vestiges of the built and cultural environment, including monuments, historic public buildings and homes, farms, castles and cathedrals, museums, and archaeological ruins and relics.<sup>39</sup>

Other scholars broadly encapsulate heritage tourism as “a subgroup of tourism, in which the main motivation for visiting a site is based on the place’s heritage characteristics according to the tourist’s perceptions of their own heritage”.<sup>40</sup> Heritage tourism encompasses both the tangible and intangible aspects (of both heritage and culture) and can essentially be defined from both a demand and a supply perspective.<sup>41</sup> One holistic definition which includes the physical, emotional and spiritual aspects, says that

“heritage tourism often refers to visiting places of historical interest and significance such as castles, monuments and museums” and involves “participation in and experience of those activities, rituals and routines by which a community is defined”.<sup>42</sup>

For other scholars, a different focus is given. For example, in the recent work of Park it is considered that heritage tourism “is predominantly concerned with exploring both material (tangible) and immaterial (intangible) remnants of the past. Importantly, heritage is not a fixed or static outcome of the past, particularly when it is presented and represented in the context of tourism”.<sup>43</sup> Arguably, there are various categories of what constitutes heritage (tangible or intangible elements inherited from one’s own past); heritage can be natural (ecological), cultural (paleoanthropological and historical), or industrial (mining and manufacturing) in its extent.<sup>44</sup> Overall, it is observed that there is an increasing emphasis in looking at the inter-relationships and synergies between heritage studies and heritage tourism.<sup>45</sup> This said, whichever definition of heritage a curator or heritage manager adopts or conceptualises, what a heritage tourist expects or hopes to see and experience at a heritage site, it is argued, will strongly influence the success and sustainability of the heritage and heritage tourist experience.<sup>46</sup>

Heritage tourism can be viewed as an emotional/spiritual experience that gives both domestic and international guests an opportunity to *feel, experience and understand* the unique customs of a particular constituency’s heritage while enjoying and exploring the history of that people or country.<sup>47</sup> Many international scholars view heritage tourism as being about “public heritage spaces, museums and the like [which] have a very specific historical genealogy that derives from a very particular set of imperatives and conservative means of looking at things”.<sup>48</sup> Heritage, therefore, is the complete variety of our innate culture, traditions, customs, monuments and historical items. Most critically, this notion is the variety of modern behaviour and activities from which we extract meanings. It is our way of living that includes preserving and restoring a collection of our ancient historical valuables, regardless of whether they are concrete; or a set of ideas and memories in forms of folklore, songs, dances, language; or other elements that make us who we are and how we identify with ourselves and beliefs, in relation to other people and their difference.<sup>49</sup>

Despite the different focus of each of these definitions, it shows that many factors have a critical role to play in the interpretation and description of what heritage tourism is. Furthermore, all these definitions are effective and thorough because they describe the historical relationship of people in relation to cultural and historical events and

values. Both the tangible and intangible aspect of heritage is addressed. Heritage as an all-encompassing concept, is thus interpreted in various forms and in different ways and can thereby impact upon the scope and success of heritage tourism. Battlefield tourism is a significant component of heritage tourism throughout the world.<sup>50</sup>

## Battlefield Heritage Tourism: An International Perspective

Battlefield tourism includes “visiting war memorials and war museums, ‘war experiences’, battle re-enactments and the battlefield”.<sup>51</sup> Battlefield tourism is becoming increasingly popular throughout the world.<sup>52</sup> Much research on the battlefields of First World War has been done (with 2014 having marked the centenary of First World War [1914-1918]), as many people across the world continue to visit battlefield sites.<sup>53</sup> Battlefield tourism forms part of thanatourism or what is more commonly called ‘dark tourism’.<sup>54</sup> Several reasons as to why people would want to visit places of death and destruction (such as these once were) exist.

These motivations include, inter alia:

- special interest (a personal interest someone may have in a particular site or war as a result of personal links or family associations to the event);
- thrill/risk seeking (being part of a re-enactment of the battle);
- validation (legitimising and forming approval and acceptance for or of the event);
- authenticity (not so much the realness of the event, but rather the representation of it from all perspectives);
- self-discovery (knowing what your ancestors experienced and sacrificed for you by being involved or killed in that conflict);
- iconic sites (some sites are considered seminal in history and a ‘must-see’ for tourists);
- convenience (a battlefield site is close by and coincidentally forms part of the tourists’ itinerary);
- morbid curiosity (people interested in the macabre);
- pilgrimage (people who lost loved ones in that event want to see where, what and learn about how, it took place);
- remembrance and empathy (young and old died together);
- contemplation (thinking history through for personal reflection and meaning-making);
- legitimisation (creating national pride);
- economic resurgence (creation of employment and income flows through visitation);
- discovery of heritage (where local communities discover a sense of their identities through past histories);
- acts of remembrance (honouring those who sacrificed their lives for your freedom); and
- personal aspirations (of seeking social or political prestige).<sup>55</sup>

Much of the existing research done on battlefield tourism focuses on how they are represented/imagined, as well as how they are managed or maintained.<sup>56</sup> The representation of history (and from whose perspective it is represented) is a contested concept within the literature and remains one aspect of understanding battlefields and struggle/liberation heritage tourism, which still needs further investigation.<sup>57</sup> For example, the Pacific War Battlefields have impacted many Japanese people in feeling uneasy and ashamed of their ancestors' involvement in the War.<sup>58</sup> Heritage and battlefield tourism has been attributed to the development and understanding of social memory and remembrance.<sup>59</sup> Battlefields have been studied as a memory or commemoration of the past.<sup>60</sup> It is argued "battlefield sites possess their own life cycle of meaning and nature of attraction – and with age they 'cool' to become not simply places of memorial to a recent past generation, but a place of heritage to inform future generations";<sup>61</sup> this means that they have a wider appeal to a larger audience.<sup>62</sup> It is maintained that care needs to be taken in the representation and imaging of the battlefield so as to create awareness among visitors of the sobering nature of the conflict and consequences for all involved.

Increasingly, battlefield tours have strong religious overtones around remembrance and sacrifice that are constituted and fulfilled in a pilgrimage.<sup>63</sup> Heritage custodians and tourism authorities have a suite of moral and ethical dilemmas to reconcile in portraying the history at a particular heritage site.<sup>64</sup> Another important theme within battlefield tourism is the authenticity of the experience to the tourist.<sup>65</sup> People visit battlefields for a number of reasons and "the visitor experience is thus multifaceted with an appreciation of the site as a heritage, not a specifically dark, tourism site".<sup>66</sup> Increasingly, contemporary research explores the meanings and motivations of people visiting battlefields with a "desire for learning and commemoration play(ing) an important part in motivating battlefield tourists".<sup>67</sup> Stakeholders of battlefield tourism are thus coming to the realisation that these tourists are "an emotionally sensitive, nuanced and reflexive constituency".<sup>68</sup> In this chapter, it will be shown that battlefield tourists constitute a specific niche of the cultural/heritage tourism market.<sup>69</sup>

In a recent contribution, Smit, Magagula and Fügel call for more attention to be devoted to research of South Africa's military geography.<sup>70</sup> Although battlefield tourism has been researched in many countries, few studies have focused explicitly on local tourism planning and the impacts of battlefields for local economies.<sup>71</sup> Several reasons exist in South Africa as to heritage and cultural tourism being used as an economic development tool. First, South Africa's cultural and heritage assets in terms of battlefield sites are different in character from those in developing countries. Second, many of these battlefield sites are located in remote rural areas where other economic and revenue-creating activities are limited. Third, in the South African context battlefields heritage and cultural tourism

can be a lever for small tourism enterprise development, such as the establishment of Bed & Breakfasts in local settlements. Importantly, for entry-level SMMEs to support heritage or cultural tourism little capital is required.<sup>72</sup>

## **Battlefield Tourism in South Africa – The Case of Magersfontein, Northern Cape**

Battlefields play an important role in the collective identity and history of South Africa.<sup>73</sup> In 1994, under the leadership of Nelson Mandela, when South Africa became a democracy, the government initiated a “host of memorials, monuments and heritage sites to redress the existing (apartheid) heritage landscape”.<sup>74</sup> Many of the battlefield sites throughout South Africa are declared as national heritage sites and cover some of the most important events that have shaped South African history, from “colonial clashes of the 18<sup>th</sup> and 19<sup>th</sup> Centuries to the 2<sup>nd</sup> Anglo-Boer War of 1899-1902”.<sup>75</sup>

Moeller claims battlefield tourism in South Africa has grown during the past few decades, particularly in KwaZulu-Natal and in the Northern Cape province.<sup>76</sup> In total there are over 140 sites to visit in KwaZulu-Natal, which detail the Boer, the British and the amaZulu conflicts in history.<sup>77</sup> These battles form part of South Africa’s history that “arose from colonisation by the Dutch and the British and clashes between different African societies over resources and territory”.<sup>78</sup> Van der Merwe details the significance of the battlefields in Dundee, KwaZulu-Natal, each of which has significance to South African history and impacts on South Africans’ heritage.<sup>79</sup> The Magersfontein battlefield that makes up the case study of this chapter is shown in figure 2.1. The Magersfontein battle (see figures 2.2 and 2.3) took place on 11 December 1899 and was fought between the Boers and the British. “There were 192 British dead and more than 690 wounded. The Boers lost 71 men, and a further 184 were wounded, although different reports give different figures.”<sup>80</sup>

Both domestic and foreign tourists visit such sites to pay homage to fallen ancestors and to ‘see history’ with their own eyes, experiencing the battle through the guidance of a trained and qualified tourist guide.<sup>81</sup> Venter explores several reasons for people visiting the battlefields in South Africa, although these sites predominantly have “served as places of awe and inspiration, mourning and commemoration, leisure and tourist destinations.”<sup>82</sup> Venter further suggests, “there is a growing interest in the stories, lives and experiences of those who fought and lived and those who died during times of war in far-away places. Such heritage tourism helps visitors to immerse themselves in a destination”.<sup>83</sup>





FIGURE 2.2      Magersfontein Battlefield (as seen from the Museum Vantage Point)  
*Source: Magersfontein Museum & McGregor Museum, 2017*



FIGURE 2.3      Magersfontein Battlefield Model (at the vantage point from the Museum)  
*Source: Magersfontein & McGregor Museums, 2017<sup>64</sup>*

## Local Tourism Policy, Planning and Trends in the Magersfontein Battlefield Region

This section turns to review the place of tourism, especially battlefield tourism, in local development planning through an examination of the municipal integrated development plan, as well as the tourism promotion of battlefields in local and provincial tourism policy documents which local and provincial tourism bodies produce. The Battlefield of Magersfontein is situated in the Northern Cape Province of South Africa (see figure 2.1). The region in which the battlefield site is found forms part of the Sol Plaatje Local Municipality (SPLM), which is part of the Frances Baard District Municipality (FBDM). It is very disappointing that the term ‘battlefield’ never appears in the SPLM Integrated Development Plan. Furthermore in analysing the SPLM IDP of 2014-2017, it is dismaying that the term ‘heritage’ only appears once in the whole 45-page document. Clearly not enough emphasis and energy is placed on battlefield or heritage tourism in the Northern Cape.<sup>85</sup> Tourism is scantily mentioned in the IDP, too.

Van der Merwe has argued that IDPs need to place more emphasis on the value of heritage and cultural tourism towards the local economic development of marginal areas, such as Magersfontein Battlefield (and other battlefield tourism in South Africa).<sup>86</sup> Fortunately, the FBDM recognises the importance of battlefield tourism as it mentions Magersfontein on its website, suggesting “the Northern Cape punctuates the South African landscape beautifully, as it adds to the rugged starkness to the patchwork of diversity. The list of must-see ranges from the famous battlefields of Magersfontein and Paardeberg, to the Kimberley Ghost Trail and the Township Wonders”.<sup>87</sup>

## Heritage Tourists and the Battlefield

Undoubtedly, one factor behind this silence is the absence of evidenced-based research to inform local tourism planning.<sup>88</sup> One essential source of information – explored in this section – is the capture of data on flows of heritage tourists into the area and specifically of the views of heritage tourists on local heritage tourism developments and challenges. By looking at the different variables of: visitor numbers (see table 2.1) to the Magersfontein battlefield site; purpose of tourist trips; average tourist spending; and percentage of tourism contribution to the Gross Domestic Product – within the SPLM – a profile of the local battlefield tourism economy is provided.



TABLE 2.1 Number of visitors to the Magersfontein Museum and Battlefield Site, from 2012-2016

YEAR	NUMBER OF VISITORS
2012	4 241
2013	4 760
2014	4 169
2015	5 108
2016	4 130

Source: Marketing Department and Curator of the McGregor Museum, 2017

From table 2.1, it is evidenced that the general trend for the battlefields in the region signals a stagnation or decline over time. Furthermore declining visitor numbers and findings of a declining or stagnation in the tourism industry from the key stakeholder interviews is confirmed by the IHS Global Insight data on purpose of travel to the Battlefield municipality. Figure 2.4 shows the reduction and stagnation in visitor numbers over time and represents the number of tourist trips undertaken for various purposes to the SPLM.

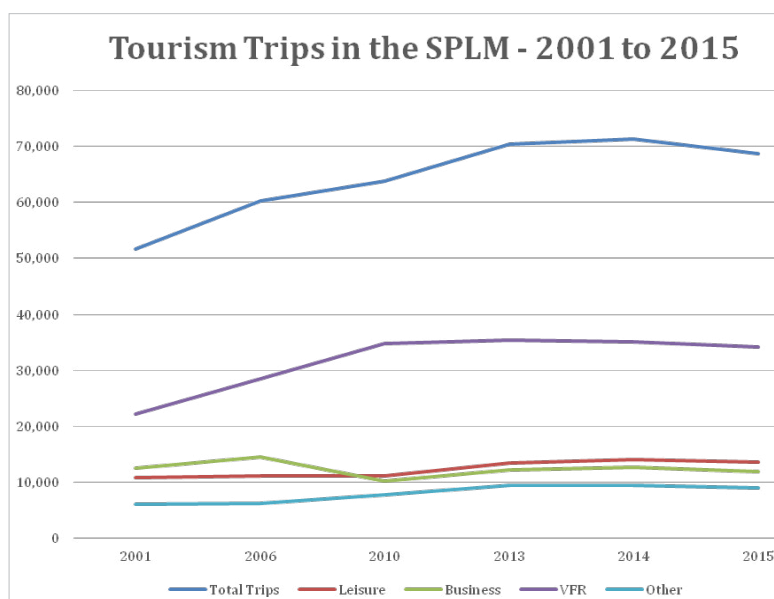


FIGURE 2.4 Number of Tourist trips for various purposes to the SPLM from 2001-2015

Source: Unpublished data from Global Insight, 2015<sup>89</sup>

## The Challenges for Developing Battlefield Tourism

Previous research with stakeholders and visitors in Dundee (in KwaZulu-Natal) sought to disclose the challenges facing battlefields tourism for promoting local development. One significant survey finding for local policy-makers was that 82% of visitors to the Battlefields only stayed over in the area for one night; the remainder were ‘simply passing through’ and chose to visit the battlefield site while in transit, or had stayed with family or friends.<sup>90</sup> This was concurred by most of the accommodation sector stakeholders interviewed in the Kimberley area. This finding has important implications for tourism spending, as well as for the benefits to the local accommodation sector in terms of hotels, guesthouses, lodges and bed & breakfasts in battlefields regions. Such a finding corresponds with the broad picture of the weak state of the local tourism economy in most municipalities across South Africa.<sup>91</sup>

The fifty ‘heritage tourists’ interviewed at the Magersfontein battlefield site identified several management-related themes that concern them which could lead to poor attendance at heritage sites in South Africa. First, safety and security were important to visitors, many expressing “lack of security and fear of crime” (respondent 13) being an important issue. Second, many felt that some sites were too expensive and not good value for money, observing “locals cannot afford the expensive entrance fees” (respondent 4) and “a lack of interesting and knowledgeable guides is also prevalent at many sites, many guides are ignorant, placed there by local authorities and who are not qualified, (or even) registered guides” (respondent 11). Third, logistical difficulties were also a factor as the interview respondents stated, “tourists may be deterred by poor road conditions they are unfamiliar with (potholes and stray animals)” (respondent 9). Indeed, it was evident in other responses variously that “battlefields are often off the beaten track and in some places, require some effort to get to” (respondent 8).

Many respondents highlighted the lack of strategic guidance and leadership from local authorities and identified several issues relating to this. Examples of responses from interviewees were that “the truth of past events must be told without bias or manipulation” (respondent 6). Issues of concern were expressed in interviews variously; “the promotion of heritage was not prioritised and the lack of funding for the upkeep of heritage” (respondent 7); and “the sites are not properly marketed and the Heritage Agencies are doing less in promoting the sites” (respondent 13). Finally, the lack of support and the poor culture of tourism within the local communities was a further issue that was highlighted in statements that “many locals lack respect for our heritage sites and have no appreciation of our heritage” (respondent 9).

In terms of the stakeholder interviews most respondents voiced high levels of criticism towards the ineffective role of local government in promoting battlefields tourism. It was suggested that the local municipality “budgets way too little for the promotion of battlefield tourism in Kimberley” (respondent 3) and is sometimes “at loggerheads with the tourist industry. For example, it was argued that tourist guides are made to pay every time they visit a battlefield site which causes them to put up their fees with tourists and creates resentment amongst tourist guides and tourists, thus hindering the development of the battlefield tourism industry in the Northern Cape” (respondent 4).

Of concern to most stakeholders was the lack of strategic leadership and initiative from local government and bodies that ought to be promoting and driving the battlefields tourism industry. For many of the stakeholders, like accommodation owners, interviewed – most expressed a lack of trust and confidence in the local and provincial authorities with respect to the management and maintenance of tourism – which seems to be a universal problem.<sup>92</sup> Among shortcomings identified by various stakeholders are a lack of strategic direction; duplication and wastage of resources; poor budgeting; poor or non-existent marketing strategies; and lack of capacity. One stakeholder remarked: “The (battlefield tourism) product has to be de-politicised and targeted at what the visitor wants and will pay for. The sector is divided and not coordinated at this time. It has to be better promoted in a professional way and moved forward into the 21<sup>st</sup> Century” (respondent 5).

In expanding and maximising the potential of battlefields as a tourism asset, a number of policy-related suggestions were offered. It was argued by interviewees and various stakeholders that the promotion of heritage tourism should be activity-based with annual festivals, events that encompass heritage but also other things to attract people. Tourists should come for certain heritage elements and then get a wider package. Finally, marketing remains a challenge. The battlefields are not cohesively represented at the Tourism Indaba which is an international convention hosted annually at the Durban International Convention Centre.<sup>93</sup> Greater coordination and inter-sectoral agreements for working together are required to address and resolve these matters.

## Conclusion

This chapter’s specific focus was to examine battlefield tourism, a form of heritage tourism that was shown to be important in several parts of the world, using Magersfontein Battlefield and Museum as a case study. In common with international experience, visitors to battlefield sites, tourists and local stakeholders within the industry agree that the battlefield site of Magersfontein is “worthy of attention and

research for (battlefields) represent not only memories of the past, but also statements of the present and aspirations for the future”.<sup>94</sup> The results of this investigation suggest that whilst battlefields tourism in South Africa can be an asset and a lever for local economic development, the situation in the Northern Cape is that this niche of heritage tourism currently is in a state of disarray and unstable. Many of the problems facing battlefield tourism as a form of heritage tourism are similar to those that were evidenced in the investigations relating to the Cradle of Humankind and industrial heritage tourism in the cases of Cullinan and Kimberley.<sup>95</sup> It was revealed that several challenges must be addressed to enhance the potential for battlefield tourism to be an important local development vehicle. Among the major problems highlighted are lack of planning; strategic direction and management; and political will to improve the situation and solve problems that affect each of the battlefield sites. These are policy issues that must be dealt with at both local and provincial government level if heritage tourism is to be a responsible and sustainable niche of the national tourism economy.<sup>96</sup>

The limits of battlefield tourism as a contemporary driver for local development were shown in this chapter. It is evident that the battlefields are attracting less of the smaller surviving generation that are immediately interested and affected by the history and heritage of these conflicts. Accordingly, attention must be given to more segmented and innovative marketing, the development of higher-quality accommodation within these rural areas, improved education of guides at sites and expanding the knowledge of local tourism officers.<sup>97</sup>

Expanded levels of funding and strategic grants from local and provincial government can also go a long way to help sustain and support the work being done by the McGregor Museum in Kimberley (responsible for the Magersfontein Battlefield and Museum). Above all, chronic problems exist with the capacity of local government to support tourism development including the niche of battlefield tourism. As a whole, these issues confirm more broadly the capacity shortcomings of many local governments in South Africa with respect to tourism development, planning and management.<sup>98</sup> The Sol Plaatje Local Municipality and the Frances Baard District Municipality are typical of local governments across South Africa, which are struggling with the multiple challenges of planning for responsible and sustainable tourism development.<sup>99</sup> Policy and legislative processes are in place but the heritage tourism sector needs to take on some more innovative approaches to segmented marketing. The use of digital and other more technological best practices in cultural and heritage tourism should be applied from countries such as Australia, New Zealand and the United States which have used social media and Apps to grow and deepen their heritage tourism markets. This can, and should, be replicated in policy initiatives in South Africa. One promising step is from the

Western Cape which is taking the lead in this respect with their 'Love Cape Town' App and South African Tourism (SAT) for utilising the Madiba's Journeys App as a lever to showcase and develop the 'struggle' or liberation heritage in South Africa.

Further research needs to be done on how battlefield tourism fits into the history of South Africa's 'liberation struggle'. This said, there is an important and unexplored suite of issues that could be supported by academic research and to inform policy development. Among a range of topics is how the distressed areas in South Africa could better utilise heritage tourism (like that of battlefield tourism) to grow their local economies. The imperative for further work on local development impacts of South Africa's critical heritage assets around the 'struggle' or the liberation heritage potential for heritage tourism remains a key area of concern.

## ENDNOTES AND REFERENCES

1. Timothy, D.J. & Boyd, S.W (eds.). 2003. *Heritage Tourism*. Essex: Pearson Education.  
 Timothy, D.J. & Boyd, S.W. 2006. Heritage tourism in the 21<sup>st</sup> century: Valued traditions and new perspectives. *Journal of heritage tourism*, 1:1-16. <https://doi.org/10.1080/17438730608668462>  
 Timothy, D.J (ed.). 2007. *Managing Heritage and Cultural Resources*. London: Ashgate.;  
 Timothy, D.J. & Nyaupane, G.P (eds.). 2009. *Cultural Heritage and Tourism in the Developing World – A Regional Perspective*. London: Routledge. <https://doi.org/10.4324/9780203877753>  
 Park, H.Y. 2014. *Heritage Tourism*. London: Routledge.;  
 Waterton, E. & Watson, S. 2015. *The Palgrave Handbook of Contemporary Heritage Research*. Hampshire: Palgrave Macmillan. <https://doi.org/10.1057/9781137293565>
2. Cela, A.; Lankford, S. & Knowled-Lankford, J. 2009. Visitor spending and economic impacts of heritage tourism: a case study of the Silos and Smokestacks National Heritage Area. *Journal of Heritage Tourism*, 4:245-256. <https://doi.org/10.1080/17438730802139269>
3. Hoogendoorn, G. & Rogerson, C.M. 2015. Tourism geography in the global South: New South African perspectives. *South African Geographical Journal*. pp. 101-110. <https://doi.org/10.1080/03736245.2015.1034574>  
 Visser, G. 2016. South African tourism geographies: progress and prospects. *South African Geographical Journal*, 98:428-438. <https://doi.org/10.1080/03736245.2016.1208583>  
 Van der Merwe, C.D. 2016a. The Organisation, Geography and Local Development Impacts of Heritage Tourism in South Africa. Unpublished PhD Thesis. University of Johannesburg, South Africa.
4. National Department of Tourism. 2010. *Proposed Approach to Developing a Culture and Tourism Strategy for South Africa in the Context of Rural Development*. Presentation to Parliamentary Portfolio Committee Workshop.
5. RSA. 1996a. *The Importance of Heritage in Economic Development in South Africa*. Department of Arts and Culture. Pretoria: Government Printers.;  
 RSA. 1996b. *White Paper on Arts, Culture and Heritage*. Pretoria, South Africa: Government Printers.;  
 RSA. 1996c. *The White Paper on the Development and Promotion of Tourism in South Africa*. Pretoria: Government Printers.;  
 RSA. 1999a *The National Heritage Council Act* (No. 11). Pretoria: Government Printers.;  
 RSA. 1999b. *The National Heritage Resources Act* (No. 25). Pretoria: Government Printers.;  
 RSA. 1999c. *World Convention Act* (No. 49). Pretoria: Government Printers.;  
 RSA. 2010. *The Importance of Heritage in Economic Development in South Africa*. Department of Arts and Culture. Pretoria: Government Printers.;  
 RSA. 2012a. *Domestic Tourism Growth Strategy*. Pretoria: Government Printers.;  
 RSA. 2012b. *National Heritage and Cultural Tourism Strategy*. Pretoria: Government Printers.;  
 RSA. 2012c. *National Tourism Sector Strategy*. Pretoria: Government Printers.;

- RSA. 2012d. *Rural Tourism Strategy*. Pretoria: Government Printers,;
- RSA. 2013. *Revised White Paper on Arts, Culture and Heritage*. Pretoria, South Africa: Government Printers,;
- RSA. 2014. *Tourism Act* (No. 3). Pretoria: Government Printers,;
- RSA. 2015. *Revised White Paper on Arts, Culture and Heritage – DRAFT*. Pretoria: Government Printers.
6. Rogerson, C.M. 2002a Tourism-led Local Economic Development: The South African Experience. *Urban Forum*. pp. 96-119,;
  - Rogerson, C.M. 2014. Reframing place-based economic development in South Africa: the example of Local Economic Development. *Bulletin of Geography. Socio-economic Series*, 24:203-218. <https://doi.org/10.2478/bog-2014-0023>
  - Rogerson, C.M. 2015a. Restructuring the geography of domestic tourism in South Africa. *Bulletin of Geography. Socio-economic Series*, 29:119-135,;
  - Rogerson, C.M. 2015b. Tourism and regional development: The case of South Africa's distressed areas. *Development Southern Africa*, 32:277-291. <https://doi.org/10.1080/0376835X.2015.1010713>
  - Nel, E. & Rogerson, C.M. 2016. Re-engaging with spatial economic development: The recent experience of regional and local economic development in South Africa. *Local Economy*, 31:3-8. <https://doi.org/10.1177/0269094215623726>
  - Rogerson, C.M. & Van der Merwe, C.D. 2016. Heritage tourism in the global South: Development impacts of the Cradle of Humankind World Heritage Site, South Africa. *Local Economy*, 3:234-248. <https://doi.org/10.1177/0269094215614270>
  - Van der Merwe, 2016a, op. cit.
  7. Light, D. 2015. Heritage and Tourism. In: E. Waterton & S. Watson (eds.), *The Palgrave Handbook of Contemporary Heritage Research*. London: Palgrave MacMillan. pp. 144-158. [https://doi.org/10.1057/9781137293565\\_9](https://doi.org/10.1057/9781137293565_9)
  8. Jansen-Verbeke, M. & McKercher, B. 2010. The tourism destiny of World Heritage Cultural Sites. In: D.G. Pearce & R.W. Butler (eds.), *Tourism Research: A 20-20 Vision*. Oxford: Goodfellow Publishing,;
  - Sun, Y.; Jansen-Verbeke, M.; Min, Q. & Cheng, S. 2011. Tourism Potential of Agricultural Heritage Systems. *Tourism Geographies*, 13(1):112-128. <https://doi.org/10.1080/14616688.2010.516400>
  - Park, 2014, op. cit.
  9. MCCamley, C. & Gilmore, A. 2017. Aggravated fragmentation: A case study of SME behaviour in two emerging heritage tourism regions. *Tourism Management*, 60:81-91. <https://doi.org/10.1016/j.tourman.2016.11.016>
  10. Galla, A. 1998. The Tshwane Declaration: setting standards for heritage tourism in South Africa. *Museum International*, 50:38-42. <https://doi.org/10.1111/1468-0033.00175>
  11. RSA, 1996c, op. cit.
  12. RSA, 1996a, op. cit.
  13. RSA, 2012c, op. cit.



14. RSA, 2012b, op. cit.
15. RSA, 2012b, op. cit., p. 10.
16. Van der Merwe, C.D. 2013. The Limits of Urban Heritage Tourism in South Africa: The Case of Constitution Hill, Johannesburg. *Urban Forum*, 24:573-588.;
- Van der Merwe, C.D. & Rogerson, C.M. 2013. Industrial heritage tourism at the 'Big Hole', Kimberley, South Africa. *African Journal for Physical, Health Education, Recreation and Dance (AJPHRD)*, 2:155-171.;
- Khumalo, T.; Sebatlelo, P. & Van der Merwe, C.D. 2014. 'Who is a heritage tourist'? A comparative study of Constitution Hill and the Hector Pieterse Memorial and Museum, Johannesburg, South Africa. *African Journal of Hospitality, Tourism and Leisure*, 3:1-13.;
- Van der Merwe, C.D. 2014. Battlefields Tourism: The status of heritage tourism in Dundee, South Africa. In: C.M. Rogerson & D. Szymańska (eds.), *Bulletin of Geography. Socio-economic Series*, No. 26. Toruń: Nicolaus Copernicus University. pp. 121-139.;
- Rogerson & Van der Merwe, 2016, op. cit.;
- Masilo, H. & Van der Merwe, C.D. 2016. Heritage tourists' experiences of 'Struggle Heritage' at Liliesleaf Farm Museum and the Hector Pieterse Memorial & Museum South Africa. *African Journal of Hospitality, Tourism and Leisure*, 5:1-20.;
- Van der Merwe, C.D. 2016b. Tourist guides' perceptions of cultural heritage tourism in South Africa. *Bulletin of Geography. Socio-economic Series*, 34:117-130.
17. Van der Merwe, 2016a, op. cit.
18. Ibid.
19. Austin, N. 2002. Managing Heritage Attractions: Marketing Challenges at Sensitive Historical Sites. *International Journal of Tourism Research*, 4:447-457. <https://doi.org/10.1002/jtr.403>
- Hampton, M.P. 2005. Heritage, Local Communities and Economic Development. *Annals of Tourism Research*, 32:735-759. <https://doi.org/10.1016/j.annals.2004.10.010>
20. Van der Merwe, 2016b, op. cit.
21. Van der Merwe & Rogerson, 2013, op. cit.;
- Khumalo et al., 2014, op. cit.;
- Masilo, H. 2016. Heritage Tourism in South Africa: the case of Liliesleaf Farm and the Hector Pieterse Memorial and Museum. Unpublished Master of Science. Dissertation, University of the Witwatersrand, Johannesburg.
22. IHS Global Insight provides the most comprehensive economic, financial and political coverage of countries, regions and industries available from any source – covering over 200 countries and spanning more than approximately 170 industries – using a unique combination of expertise, models, data and software within a common analytical framework to support planning and decision making. [Online]: <https://globalsso.ihs.com> [Accessed 30 August 2018].
23. Van der Merwe, 2014, op. cit.;
- Van der Merwe, 2016a, op. cit.;

- Van der Merwe, 2016b, op. cit.
24. Timothy & Boyd, 2003, op. cit.;  
Waterton & Watson, 2015a, op. cit.;  
Staiff, R.; Bushell, R. & Watson, S (eds.). 2013. *Heritage and Tourism: Place, encounter and engagement*. London: Routledge.
  25. Park, 2014, op. cit.
  26. Johnson, N.C. 2015. Heritage and Geography. In: E. Waterton & S. Watson (eds.), *The Palgrave Handbook of Contemporary Heritage Research*. London: Palgrave MacMillan. pp. 159-170.  
<https://doi.org/10.1016/j.annals.2004.10.010>
  27. Timothy & Nyaupane, 2009, op. cit.
  28. Orbasli, A. & Woodward, S. 2009. Tourism and Heritage Conservation. In: T. Jamal & M. Robinson (eds.), *The SAGE handbook of Tourism Studies*. Los Angeles: SAGE.  
<https://doi.org/10.4135/9780857021076.n18>
  29. Light, 2015, op. cit.
  30. Ibid., p. 148.
  31. Ibid., p. 153.
  32. Waterton & Watson, 2015, op. cit.
  33. Light, 2015, op. cit., p. 144.
  34. Waterton & Watson, 2015, op. cit., p. 1.
  35. Ibid., p. 4.
  36. Southall, C. & Robinson, P. 2011. Heritage Tourism. In: P. Robinson, S. Heitmann & P. Dieke (eds.), *Research Themes for Tourism*. Wallingford: CABI.
  37. Jansen-Verbeke, M. 2007. Industrial Heritage: A nexus for sustainable tourism development. *Tourism Geographies*, 1:70-85. <https://doi.org/10.1080/14616689908721295>  
Jansen-Verbeke & McKercher, 2010, op. cit.;  
Sun et.al., 2011, op. cit.;  
Marson, D. 2011. From Mass Tourism to Niche Tourism. In: P. Robinson, S. Heitmann & P. Dieke (eds.), *Research Themes for Tourism*. Wallingford: CABI.
  38. Marson, 2011, op. cit., p. 9.
  39. Timothy & Nyapuane, 2009, op. cit., pp. 3-4.
  40. Poria, Y.; Butler, R. & Airey, D. 2001. Clarifying Heritage Tourism. *Annals of Tourism Research*, 28:1047-1049. [https://doi.org/10.1016/S0160-7383\(00\)00069-4](https://doi.org/10.1016/S0160-7383(00)00069-4)
  41. Smith, L. & Akagawa, N. 2008. *Intangible Heritage*, London: Routledge.  
<https://doi.org/10.4324/9780203884973>  
Southall & Robinson, 2011, op. cit.;  
Waterton & Watson, 2015, op. cit.
  42. Southall & Robinson, 2011, op. cit., p. 176.

43. Park, 2014, op. cit., p. 1.
44. Timothy & Boyd, 2003, op. cit.;  
Timothy & Boyd, 2006, op. cit.;  
Timothy, D.J. 2011. *Cultural Heritage and Tourism: An Introduction*. Bristol: Channel View Publications.
45. Timothy, 2011, op. cit.;  
Waterton & Watson, 2015, op. cit.
46. Boyd, S. 2000. 'Heritage' Tourism in Northern Ireland: Opportunity Under Peace. *Current Issues in Tourism*, 3:150-174. <https://doi.org/10.1080/13683500008667871>
47. Graham, B. & Howard, P. 2008. Heritage and Identity. In: B. Graham & P. Howard (eds.), *The Ashgate Research Companion to Heritage and Identity*.
48. Weiss, L. 2007. Heritage-making and political identity. *Journal of Social Archaeology*, 7:413-431. <https://doi.org/10.1177/1469605307081400>
49. Weiss, 2007, op. cit.;  
Graham & Howard, 2008, op. cit.
50. Staiff et al., 2013, op. cit.;  
Park, 2014, op. cit.
51. Dunkley, R.; Morgan, N. & Westwood, S. 2011. Visiting the trenches: Exploring meanings and motivations in battlefield tourism. *Tourism Management*, 32:860-868. <https://doi.org/10.1016/j.tourman.2010.07.011>
52. Fallon, P. & Robinson, P. 2016. 'Lest we forget': a veteran and son share a 'warfare tourism' experience. *Journal of Heritage Tourism*. pp. 1-15. <https://doi.org/10.1080/1743873X.2016.1201087>
53. Seaton, A.V. 2000. "Another Weekend Away Looking for Dead Bodies ... ": Battlefield Tourism on the Somme and in Flanders. *Tourism Recreation Research*, 25:63-77. <https://doi.org/10.1080/02508281.2000.11014926>  
  
Clarke, P. & Eastgate, A. 2011. Cultural Capital, Life Course Perspectives and Western Front battlefield tours. *Journal of Tourism and Cultural Change*, 9:31-44. <https://doi.org/10.1080/14766825.2010.527346>  
  
Winter, C. 2009. Tourism, Social Memory and the Great War. *Annals of Tourism Research*, 36:607-626. <https://doi.org/10.1016/j.annals.2009.05.002>  
  
Winter, C. 2012. Commemoration of the Great War on the Somme: Exploring Personal Connections. *Journal of Tourism and Cultural Change*, 10:248-263. <https://doi.org/10.1080/14766825.2012.694450>  
  
Winter, C. 2016. Social memory and battle names: Exploring links between travel, memory and the media. *Tourism and Hospitality Research*, 16:242-253. <https://doi.org/10.1177/1467358415624006>
54. Yan, B.-J.; Zhang, J.; Zhang, H.-L.; Lu, S.-J. & Guo, Y.-R. 2016. Investigating the motivation – experience relationship in a dark tourism space: A case study of the Beichuan earthquake relics, China. *Tourism Management*, 53:108-121. <https://doi.org/10.1016/j.tourman.2015.09.014>  
  
Kokkranikal, J.; Yang, Y.S.; Powell, R. & Booth, E. 2016. Motivations in Battlefield Tourism: The Case of '1916 Easter Rising Rebellion', Dublin. *Tourism and Culture in the Age of Innovation*. Springer.

55. Ryan, C. 2007. *Battlefield Tourism: History, Place and Interpretation*, Amsterdam: Elsevier.  
<https://doi.org/10.1016/B978-0-08-045362-0.50024-5>  
Winter, 2009, op. cit.;  
Clarke & Eastgate, 2011, op. cit.;  
Winter, 2012, op. cit.;  
Kim, S. & Butler, G. 2014. Local Community Perspectives Towards Dark Tourism Development: The case of Snowtown, South Australia. *Journal of Tourism and Cultural Change*, 13:78-79.  
<https://doi.org/10.1080/14766825.2014.918621>  
Lee, Y-J. 2016. The Relationships Amongst Emotional Experience, Cognition and Behavioural Intention in Battlefield Tourism. *Asia Pacific Journal of Tourism Research*, 21:697-715.  
<https://doi.org/10.1080/10941665.2015.1068195>  
Winter, 2016, op. cit.
56. Ryan, 2007, op. cit.;  
Zhang, J.J. 2010. Of Kaoliang, Bullets and Knives: Local Entrepreneurs and the Battlefield Tourism Enterprise in Kinmen (Quemoy), Taiwan. *Tourism Geographies*, 12:395-411.  
<https://doi.org/10.1080/14616688.2010.494685>  
Millar, S. 2016. Heritage management for heritage tourism. In: S. Medlik (ed.), *Managing Tourism*. Oxford: Butterworth-Heinemann.
57. Winter, 2016, op. cit.;  
Baines, G. 2007. The Master Narrative of South Africa's Liberation Struggle: Remembering and Forgetting 16 June 1976. *International Journal of African Historical Studies*, 40:283-302.;  
Bialostocka, O. 2013. *Liberation Heritage Route: Reminiscent of the Painful Past or a Road to the Future?* Pretoria: Policy Brief, Africa Institute of South Africa.;  
Bialostocka, O. 2014. Using the past to build the future: a critical review of the Liberation Heritage Route (LHR) project of South Africa. *Africa Insight*, 44:94-107.;  
Naef, P. & Ploner, J. 2016. Tourism, conflict and contested heritage in former Yugoslavia. *Journal of Tourism and Cultural Change*, 14:181-188. <https://doi.org/10.1080/14766825.2016.1180802>
58. Cooper, M. 2006. The Pacific War Battlefields: Tourist Attractions or War Memorials? *International Journal of Tourism Research*, 8:213-222. <https://doi.org/10.1002/jtr.566>
59. Lloyd, D.W. 1998. *Battlefield Tourism: Pilgrimage and the Commemoration of the Great War in Britain, Australia and Canada, 1919-1939*. London: Bloomsbury.;  
Marshall, S. 2006. Visualizing Memories: The Hector Pieterse Memorial in Soweto. *Visual Anthropology*, 19:145-169. <https://doi.org/10.1080/08949460600598695>  
Marshall, S. 2014. Tourism and Remembrance: The Journey into the Self and Its Past. *Journal of Tourism and Cultural Change*, 12:335-348. <https://doi.org/10.1080/14766825.2014.890208>  
West, B. 2016. *War Memory and Commemoration*. London: Taylor & Francis.  
<https://doi.org/10.4324/9781315572802>
60. Leopold, T. 2007. A Proposed Code of Conduct for War Heritage Sites. In: C. Ryan (ed.), *Battlefield Tourism: History, Place and Interpretation*. Amsterdam: Elsevier.  
<https://doi.org/10.1016/B978-0-08-045362-0.50009-9>

- Iles, J. 2008. Encounters in the Fields – Tourism to the Battlefields of the Western Front. *Journal of Tourism and Cultural Change*, 6:138-254. <https://doi.org/10.1080/14766820802376299>
- Winter, 2012, op. cit.;
- West, 2016, op. cit.
61. Ryan, C. 2007. *Battlefield Tourism: History, Place and Interpretation*, Amsterdam: Elsevier. p. 207.
  62. Ryan, 2007, op. cit.;
  - Tourism KwaZulu-Natal. Dark Tourism. 2004. What is it? *Occasional paper No. 24*. Durban, South Africa.
  63. Clarke & Eastgate, 2011, op. cit.
  64. Tourism KwaZulu-Natal, 2004, op. cit.
  65. Ryan, 2007, op. cit.;
  - Winter, 2009, op. cit.;
  - Miles, S. 2014. Battlefield Sites as Dark Tourism Attractions: An Analysis of Experience. *Journal of Heritage Tourism*, 9:134-147. <https://doi.org/10.1080/1743873X.2013.871017>
  - Gieling, J. & Ong, C-E. 2016. Warfare tourism experiences and national identity: The case of Airborne Museum 'Hartenstein' in Oosterbeek, the Netherlands. *Tourism Management*, 57:45-55. <https://doi.org/10.1016/j.tourman.2016.05.017>
  66. Miles, 2014, op. cit., p. 145.
  67. Dunkley et al., 2001, op. cit., p. 860.
  68. Ibid., p. 866.
  69. Henama, U.; Jansen van Rensburg, M. & Nicolaides, A. 2016. Nkandla: the unexplored frontier for heritage tourism to Zululand, South Africa. *African Journal of Hospitality, Tourism and Leisure*, 5:1-16.
  70. Smit, H.A.P.; Magula, H.B. & Flügel, T.J. 2016. South African Military Geography: advancing from the trenches. *South African Geographical Journal*, 98:417-427. <https://doi.org/10.1080/03736245.2016.1208582>
  71. Taru, P.; Chingombe, W. & Mukwada, G. 2014. A Bullet Laden Park: Potential for Battlefield Tourism in the Golden Gate Highlands National Park. *African Journal of Hospitality, Tourism and Leisure*, 2:1-9.
  72. Tourism KwaZulu-Natal. 2008. Cultural and Heritage Tourism – An Important Economic Development Tool. *Occasional paper No. 62*. Durban, South Africa.;
  - Van der Merwe, 2014, op. cit.;
  - Van der Merwe, 2016a, op. cit.;
  - Van der Merwe, 2016b, op. cit.
  73. Tourism KwaZulu-Natal. n.d. *KwaZulu-Natal Travel & Tourism Guide*. Durban, South Africa.;
  - Venter, D. 2011. Battlefield tourism in the South African context. *African Journal of Hospitality, Tourism and Leisure*, 1:1-5.;

- Venter, D. 2017. Examining military heritage tourism as a niche tourism market in the South African context. *African Journal of Hospitality, Tourism and Leisure*, 6(1):1-19.
74. Marschall, S. 2007. Constructing Identity through Cultural and Heritage Tourism in South Africa. In: B. Wishtemi, A. Spencely & H. Wels (eds.), *Culture and Community: Tourism Studies in Eastern and Southern Africa*. Amsterdam: Rozenberg Publishers. p. 88.
75. Von der Heyde, N. 2013. *Field Guide to the Battlefields of South Africa*, Cape Town: Struik Travel & Heritage. p. 12.
76. Moeller, M. 2005. *Battlefield Tourism in South Africa with Special Reference to Isandlwana and Rorke's Drift, KwaZulu-Natal*. MPhil, University of Pretoria, South Africa.
77. Battlefields Route. 2014. Explore the largest concentration of Battlefields and Game Parks in Southern Africa. In: *Battlefields Route KwaZulu-Natal* (ed.). South Africa.; Battlefields Route. n.d. Explore the largest concentration of Battlefields and Game Parks in Southern Africa. KwaZulu-Natal;  
Rattray, D. & Greaves, A. 2013. *David Rattray's Guidebook to the Anglo-Zulu War Battlefields*. Johannesburg: Jonathan Ball Publishers.;  
Van der Merwe, 2014, op. cit.
78. Von der Heyde, 2013, op. cit., p. 14.
79. Van der Merwe, 2014, op. cit.
80. Von der Heyde, 2013, op. cit., p. 265.
81. Van der Merwe, 2016a, op. cit.
82. Venter, 2011, op. cit., p. 4.
83. Venter, 2017, op. cit., p. 13.
84. The author wishes to thank Sunette Swanepoel, Marie Lodewyk and Robert Hart – at the McGregor Museum (in Kimberley) and the management and staff of Magersfontein Museum – for their help, for the photographs, and documentary evidence used in this research.
85. Sol Plaatje Local Municipality. 2012. Integrated Development Plan (IDP). Pretoria: Government Printers.;  
Sol Plaatje Local Municipality. 2017. Integrated Development Plan (IDP). [Online]: <https://bit.ly/2uqPibk> [Accessed 19 October 2017].
86. Van der Merwe, 2014, op. cit.;  
Van der Merwe, 2016b, op. cit.
87. Frances Baard District Municipality. 2012. Integrated Development Plan (IDP): 2012/13 and 2013/14. Government Printers.; Frances Baard District Municipality. 2013 Tourism in Kimberley [Online]: <http://www.francesbaard.gov.za/tourism/abouttourism.html> [Accessed 2 June 2013].
88. Van der Merwe, 2016b, op. cit.
89. IHS Global Insight. 2015a. Regional eXplorer (ReX) – a unique database for analysing South Africa's sub-national socio-economic data [Online]: <http://www.ihsglobalinsight.co.za/About/> [Accessed 15 January 2015];  
IHS Global Insight. 2015b. Estimating tourist trips and bednights. Internal document, IHS Global Insight. Pretoria, South Africa.



90. Van der Merwe, 2014, op. cit.
91. Van der Merwe, 2016b, op. cit.
92. Millar, 2016, op. cit.
93. Van der Merwe, 2014, op. cit.
94. Ryan, 2007, op. cit., p. 254
95. Rogerson & van der Merwe, 2016, op. cit.;  
Van der Merwe, C.D. & Rogerson, C.M. 2018. The Local Development Challenges of Industrial Heritage in the Developing World: Evidence from Cullinan, South Africa, *GeoJournal of Tourism and Geosites*.;  
Van der Merwe & Rogerson, 2013, op. cit.
96. Van der Merwe, 2016b, op. cit.
97. Ibid.
98. Rogerson, C.M. 2013. Tourism and Local Development in South Africa: Challenging Local Governments. *African Journal for Physical, Health Education, Recreation and Dance (AJPHERD)*, 19: 9-23.
99. Manwa et al., 2016, op. cit.;  
Van der Merwe, 2016b, op. cit.



# PART 2

Environmental Management

# Monitoring of the Implementation of Environmental Management in the Defence Force



A COMPARATIVE ANALYSIS OF TWO SOUTH AFRICAN  
NATIONAL DEFENCE FORCE MILITARY INSTALLATIONS

Bheki Magagula 

## Introduction

In recent times, environmental management has grown to become one of the top priorities of any organisation. This concern has also cascaded into the priorities of armed forces, that is, military organisations. Accordingly, the pro-active approach to military impacts on the environment was initiated by the USA Department of Defence in 1989.<sup>1</sup> Subsequently, in the mid-late 1990s, a major study was conducted by the North Atlantic Treaty Organisation Committee on the Challenges of Modern Society (NATO-CCMS) to consolidate the need for environmental responsibility and accountability in the military sector. Smit argues that, since then, there has been growing environmental awareness in the military sector;



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this has posed a considerable challenge to contemporary defence forces in regard to environmental responsibility.<sup>2</sup> Consequently, military practitioners around the world have recognised the need for sustainable utilisation of the environment in military controlled lands in ensuring that future military activities are not compromised. Furthermore, they have also realised that improvement in environmental conscientiousness is key to increased military readiness.<sup>3</sup> Therefore, the impacts of military training on the environment needs to be recognised, understood and mitigated, or reduced, to ensure that military training areas are sustainable.<sup>4</sup>

For the sustainability of military training areas to be achieved, an Environmental Management System (EMS) needs to be developed and implemented. This process requires diligence from all the military organisation's personnel, from the upper echelons down to the foot soldiers. The implementation of environmental management must be monitored to measure success or improvement over time. More importantly, however, the military organisation has to adopt or develop instruments to monitor the implementation of environmental management, as well as the necessary improvements in this regard and to identify weaknesses. Nevertheless, for the sake of the process and the instruments (or mechanisms) used to yield the desired outcomes, the capabilities of the military personnel leading the environmental management programme constitute key elements in the process. In addition, all other basic necessities such as financial resources, appropriate vehicles and infrastructure, should be made available to the designated environmental officer in the Defence Force in order to ensure the successful implementation of environmental management processes and programmes.<sup>5</sup> To date, many military organisations in different countries have established their environmental management systems and integrated environmental management considerations into their daily activities.<sup>6</sup> Consequently, those countries are currently well ahead of others in respect to military environmental management (discussed below). Some of these countries also share their knowledge/resources and experiences with those countries that are still struggling to put together plans and programmes on military environmental management.

It is the objective of this study to appraise the implementation of environmental management monitoring mechanisms at the six South African Infantry Battalion (6 SAI Bn) and the 46 SA Bde military installations of the SANDF. These two military installations were chosen based on the criteria set for the study (explained in the methodology section). This assessment is motivated by the understanding that detailed and accurate environmental reporting is imperative towards monitoring the implementation of environmental management in the defence arena.

## Contextual Background

According to Sowman et al., worldwide environmental consciousness started in the early 1970s. This was prompted by the enactment of environmental policy in 1970, by the USA.<sup>7</sup> From this period onwards, there has been an increase in environmental awareness. This awareness has intensified in recent decades, during which governments, industries and citizens across the world have become more sensitised to environmental issues and the need to manage the natural environment more systematically.<sup>8</sup>

The period from the 1980s onwards is conspicuous for the adoption of a systematic approach to environmental management and its role in dealing with environmental problems.<sup>9</sup> Thus, environmental issues have been increasingly integrated into various organisations' activities.<sup>10</sup> It is during this period that the term 'sustainable development' was coined.<sup>11</sup> The idea was that all kinds of development and utilisation of the environment should meet the needs of the present generation, without compromising the ability of future generations to meet their own needs.<sup>12</sup>

Originally, the concept of sustainable development was coined and based on three pillars, which are: economic, social and environmental sustainability.<sup>13</sup> Recently, 'cultural sustainability' has emerged as the fourth pillar (isolated from the social dimension) of sustainable development.<sup>14</sup> Cultural sustainability advocates for the incorporation of the local culture into development planning or the utilisation of natural resources.<sup>15</sup>

The conception and acceptance of sustainable development has led to the commencement and development of various environmental management tools and techniques. These tools include: environmental management systems, environmental auditing, environmental labelling, life-cycle assessment, environmental indicators, environmental reporting and environmental charters, to name a few.

From the 1970s until the late 1990s, military-related environmental impacts did not receive as much attention as those of other sectors, especially during peace time.<sup>16</sup> This however does not include the United States Department of Defence (USA DoD). The USA declared its environmental strategy in the year 1991 to be exemplary in environmental management.<sup>17</sup> This emanated from the realisation that the military sector's environmental impact far exceeds that of most other government departments.<sup>18</sup> In the past, military sectors were not obligated to comply with environmental laws; for this reason, militaries were not held accountable for any damage they inflicted on the environment.

A major paradigm shift in the management of the environment by defence forces is noted in the late 1990s. In 1996, NATO-CCMS initiated a pilot project to investigate the practicability of introducing EMS in defence forces.<sup>19</sup> This study rightly concluded that the implementation of EMS in military organisations is necessary and most desirable given the aggressive nature of military activities. The report further argues that the formulation and adoption of EMS for the defence forces should ensure compliance with the environmental legislation of the country concerned and, furthermore, it should ensure commitment to the protection of the environment from the aggressive nature of military activities.<sup>20</sup>

The publication of NATO-CCMS's final report [2000] led to all military practitioners realising that it would be beneficial to implement EMS in the military.<sup>21</sup> Since the publication of the NATO-CCMS report, many defence forces in different countries started to develop and implement EMS in efforts to protect the environment and ensure the sustainability of military training areas, as well as to comply with legal requirements. Wang and Wu indicate that some of the countries have developed and implemented ISO 14001 based EMS, or they have appropriately planned for environmental management in their respective defence forces.<sup>22</sup>

Countries such as the United Kingdom, the Netherlands, the United States of America, Canada, Portugal, South Africa, the Slovak Republic and India have implemented EMS in their respective armed forces.<sup>23</sup> Countries that have made significant inroads into the incorporation of environmental considerations into their military activities through the implementation of EMS, are the United States of America, Australia, Canada, Sweden, the United Kingdom and Portugal.<sup>24</sup> Wang and Wu state that the Australian Defence Force adopted its EMS in 2001, so as to incorporate environmental concerns into the daily activities of the military.<sup>25</sup> Further, Ramos and De Melo state that the USA started piloting the implementation of EMS as early as 1997, at 16 military installations. Accordingly, the Navy's North Island Naval Air Station was the first military installation in the USA to receive ISO 14001 certification.<sup>26</sup> In 2001, the Portuguese military organisation implemented its EMS and also received ISO 14001 certification.<sup>27</sup> Whitford and Wong argue that the adoption of ISO 14001 based EMS is associated with higher levels of environmental sustainability. A high level of environmental sustainability is critical in military controlled or used land.<sup>28</sup> While the high standard prevents degradation, it may, however, limit or even prevent realistic military training.<sup>29</sup>

It must be noted that from the military point of view, there were concerns that the incorporation of environmental issues into military training activities would adversely affect military troops' proficiency in defence operations.<sup>30</sup> For the military to achieve military readiness, they are always expected to conduct comprehensive and realistic



combat training to refine soldiers' proficiency to carry out military missions.<sup>31</sup> These concerns were somehow alleviated in the first phase (Phase I) of NATO-CCMS's study on environmental awareness in the armed forces. This study focused on a range of concerns and interests on the impact of armed forces on the environment and the desire to contribute to the protection of the environment. Consequently, educational material including pamphlets containing guidelines to encourage environmental awareness within armed forces were produced.<sup>32</sup>

Therefore, the NATO-CCMS's final report of Phase II states that 25 countries (representatives from the defence organisations of 25 countries) participated in a workshop focused on the environmental aspects of military compounds held in Vienna, Austria, in 2006.<sup>33</sup> These countries included nine collaborating countries: Albania, Armenia, Austria, Azerbaijan, Croatia, Finland, Georgia, the Republic of Macedonia and Ukraine. The participation of the 25 countries in the workshop affirms their commitment to proactive environmental management by the military, as it has become a global concern.<sup>34</sup> This clearly indicates that countries share their ideas, knowledge and experiences on the development and implementation of EMS in the defence forces.<sup>35</sup>

Similarly, a bilateral partnership on defence and environmental management, between South Africa and the USA, had assisted the South African Department of Defence and Military Veterans (DoDMV) to develop its EMS for the SANDF. In addition, numerous other documents that address environmental management in the defence arena have since been produced. Through this partnership, the following documents have been developed: *Conversion of Military Bases in South Africa*;<sup>36</sup> *Military Integrated Training Range Management Guidebook*;<sup>37</sup> *Guidebook on the Development and Implementation of Environmental Education and Training in the Military*;<sup>38</sup> and *Guidebook on Environmental Impact Assessment in the Military*.<sup>39</sup> Furthermore, a *Guidebook on Environmental Considerations during Military Operations* was published in 2006.<sup>40</sup>

All these documents are evidence that the SANDF is committed to protect the environment, reduce environmental impact and ensure the sustainability of its military training areas. Unfortunately, the implementation of the EMS in SANDF practices was terminated in 2007, due to the lack of progress.<sup>41</sup> The collapse of EMS implementation in the SANDF could have serious ramifications for the future of environmental management in defence, especially if the problems highlighted by Smit and Magagula regarding the implementation of EMS in defence are not addressed.<sup>42</sup> The problems range from infrastructure, lack of staff/personnel, a severe lack of funding for environmental services, to policies.<sup>43</sup> Similarly, if all the other existing documents developed through the United States of America – Republic of South Africa bilateral co-operation are not translated into action,

they will not serve the purpose for which they were developed. Undoubtedly, the SANDF faces serious challenges in meeting its obligation to protect the environment through the effective implementation of the adopted environmental management tools. This can be viewed as a threat to the medium- to long-term sustainability of military land areas in South Africa and eventually a threat to the society, especially if all the shortcomings highlighted above are not adequately addressed.<sup>44</sup>

## Methodology

The criteria used to select military installations as study areas were 'light military use', 'moderate military use' and 'heavy military use'. Based on these criteria, eight military installations were identified. Subsequently, permission to initiate the study at the selected installations was sought. Unfortunately, permission to carry out the study was only received from two military installations. These installations are the 6 South African Infantry Battalion (6 SAI) [hereafter referred to as Grahamstown Military Installation (GMI)] classified as 'light military use' and the 46 Brigade (46 Bde) [hereafter referred to as SAACTC] classified as 'heavy military use'. Thus, a multiple-case study research design was adopted to carry out the investigation of environmental management in the two military installations. A case study research approach creates an opportunity for an in-depth (extensive) investigation of the phenomenon. It also allows for collection of several data types, an element which mainly characterises case study research. Case study is one of the research methods that has stood the test of time and it predates the recently dominating mixed-research approach.<sup>45</sup> According to Heale and Twycross, data collected from multiple-case studies is more reliable than from single-case research. They further state that case studies allow for more comprehensive exploration of research questions.<sup>46</sup>

Therefore, the current study adopted a qualitative research approach, using stratified, purposive and Link-Tracing Sampling (LTS) techniques to select respondents. Gray describes stratified sampling as a technique that draws the sample from various strata.<sup>47</sup> Purposive sampling is a technique adopted to deliberately select the subjects against one or more traits in order to achieve what is believed to be a representative sample; this technique was used to select the respondents from the strata identified. According to Gray, purposive sampling may lead to the omission of vital characteristics or might be biased in selecting the sample.<sup>48</sup> However, this shortcoming was compensated for by using link-tracing (also known as snowball) sampling. Félix-Medina and Monjardin describe LTS as a sampling technique and 'chain referral sampling' approach for identifying suitable respondents.<sup>49</sup> Sheng et al. argue that LTS is the only means by which the initially sampled respondents

lead the researcher to other potential/hidden respondents within the targeted research population; this, in turn, may lead to other respondents and so on.<sup>50</sup> Thus, the majority of the respondents were identified using this technique.

Military personnel charged with the responsibility of ensuring that military activities are carried out in compliance with environmental legislation were the target respondents for this study. Accordingly, the personnel in the Environmental Management Facilities (EMFs) at GMI and SAACTC, Regional Facilities Interface Managers (RFIMs), installation managers (range managers), commanders and environmental officers at both military installations, were selected; those who agreed to participate in the study were subsequently interviewed. A total of four respondents were selected and interviewed at GMI. However, other officials declined to be interviewed because this study was not commissioned research.

To this end, interviews and official document analyses were adopted as fundamental data-collection techniques. Accordingly, the qualitative data analysis techniques used include narrative and content analysis. Content analysis is regarded by Duriau et al. as a kind of research method that exists at the interface of the qualitative and quantitative research approaches.<sup>51</sup> The United States Government Accountability Office (USA GAO) regards content analysis as a method that safeguards information against distortion.<sup>52</sup> Krippendorff states that the most obvious sources of data for content analysis are texts to which meanings are usually ascribed. These include verbal discourse, written documents and visual representations of situations or experiences.<sup>53</sup> Content analysis is a method used to analyse written, verbal and visual communications, as is the case in the current study.<sup>54</sup>

To identify the mechanisms used in the SANDF to monitor the implementation of the environmental management policy and practices within its territories, the current study analysed seven official documents. These documents include the 1<sup>st</sup> and 2<sup>nd</sup> editions of the *Environmental Implementation Plan*;<sup>55</sup> *Conversion of Military Bases in South Africa*; *Military Integrated Training Range Management Guidebook*; *Guidebook on the Development and Implementation of Environmental Education and Training in the Military* and *Guidebook on Environmental Impact Assessment in the Military. A Guidebook on Environmental Considerations during Military Operations* was also read and scrutinised for this study.

In addition, various environmental reports from the SAACTC were analysed. These reports include: the Environmental Support Plan for Exercise Para Bellum 2008; Environmental Closure Report (ECR) for Exercise Seboka and Para Bellum 2008; Environmental Closure Report: Exercise Seboka 2009; Lohatla 1 April 2010-31 March 2011; Environmental Management Plan: South African Army (SA Army) Combat Training Centre, 2011.

The data retrieved from the documents and the interviews were analysed using both content and narrative analysis. Narrative analysis is described, by Smith, as dealing only with verbal material, usually accounts of personal experience. Smith further argues that content and narrative analysis can provide information that other methods cannot extract.<sup>56</sup> Scholars like Coffey and Atkinson, Saunders et al., Liamputtong and Ezzy and Punch, regard these data analysis methods as assisting researchers to retain the integrity of the data collected, which is what the current study desired to achieve.<sup>57</sup>

## Results and Discussion

The analysis of the official environmental management documents of the SANDF revealed that the DoDMV adopted Military Integrated Environmental Management (MIEM) as a conceptual framework to guide the environmental management of the SANDF. This means that all military planning and activities must incorporate environmental concerns. Smit describes the MIEM approach as a fully integrated environmental management function wherein environmental education is an integral part of all the aspects of training and research focused on military environmental impacts.<sup>58</sup> Thus, the adoption of this model (i.e. MIEM) implies that environmental management is a part of the whole management process of the defence, rather than maintaining it as an isolated aspect thereof.<sup>59</sup>

Subsequently, seven environmental implementation monitoring mechanisms have been adopted by the defence to assess the implementation of environmental management. These mechanisms are:

1. guide to environmental compliance for commanding officers;
2. communication and ad hoc associations;
3. annual environmental management report;
4. auditing;
5. environmental review forum;
6. steering groups, working groups and advisory forums; and
7. environmental awards programme.

Consequently, the implementation of the environmental management practices of the SANDF ought to be assessed by one or more of these monitoring mechanisms. The assessment of the environmental management practice is meant to achieve three major purposes:

1. improve the environmental management profile of the SANDF;
2. evaluate the level of compliance with legal requirements; and
3. identify weaknesses in the environmental management implementation process.

It is imperative that the SANDF improves its environmental management in order to ensure the sustainability of its training areas and to be exemplary in the area of environmental protection and sustainability. This is important because the environmental impacts of the military far surpass those of all public entities put together.<sup>60</sup> Thus, the SANDF must show commitment and improvement in its management of the environment, in an effort to reduce its negative impact on the environment. This will heighten the positive influence of the defence on the environment, as proposed by Ramos et al.<sup>61</sup>

### *Guide to Environmental Compliance for Commanding Officers*

The commanding officers of the SANDF are provided with guidelines to assess environmental implementation in their respective installations. This means that the commanding officers must be heavily involved in the management of the environment in their military installation. This also implies that commanding officers ought to have significant knowledge of environmental management, since they are responsible for inculcating environmental ethics in their soldiers.<sup>62</sup> Furthermore, commanders have to work closely with installation designated environmental officers to discuss issues of environmental protection and to develop environmental management programmes.<sup>63</sup> It is understandable that the DoDMV adopted the use of guidelines towards environmental compliance for commanding officers to avoid a conflict of interests between the Designated Environmental Officer (DEO) and commanders. This approach is presented as having four principal aims, which are to:

- provide the commander with environmental management compliance guidelines;
- be utilised as a monitoring measure to ensure acceptable environmental performance;
- build capacity through developing an understanding of, and enhancing or advancing, sustainable development through environmental education; and
- serve as a training manual for the military.

This tool tasks commanding officers with the responsibility of ensuring that military training exercises are carried out in an environmentally friendly manner. As such, the DEOs in military installations are supposed to work closely with their commanding officers in relation to environmental management. The irony in this situation is that, in most cases, the majority of the DEOs are of a lower military rank to the commanders. For example, most of them are at the Corporal military rank, with the highest rank being the Major, while the Senior Staff Officers – Environmental Services are situated at various ranks such as Colonel and Captain. According to the chain of command in the military, Corporals, Colonels and Majors cannot overrule the direct order of the commander. This can lead to inadequate enforcement of compliance with legal requirements. Nevertheless, if the goal is to achieve better environmental practices, this combination can work well and the desired goal can be attained.

### *Communication and ad hoc relations*

Ramos and De Melo state that environmental performance communication and measurement is a critical component of the environmental management process in the defence.<sup>64</sup> This mechanism was adopted to foster interaction between SANDF environmental personnel and other provincial and national departments regarding the monitoring and implementation of environmental management practices. Ramos et al. argue that effective communication is one of the environmental performance indicators in the defence sector.<sup>65</sup> Unfortunately, at the GMI, there was no designated environmental officer for more than two years. Therefore, environmental reporting and communication on the environmental activities at this military installation have been negatively affected.

This situation can be argued to be an indication of a lack of environmental commitment on the part of DoDMV. In this regard, Neves et al. argue that the successful implementation of the EMS depends on the commitment of all levels and functions of the organisation, especially that of senior management.<sup>66</sup> This downplays the effectiveness of the MIEM as a concept to deal with environmental management issues in the defence. In addition, this indicates that there is a lack of proper planning on the part of the DoDMV. Hens et al. argue that the implementation of managerial instruments starts with good planning, followed by communication and co-operation.<sup>67</sup>

This argument is valid, in this case, in that poor environmental planning and communication on environmental management practices will not improve the defence's environmental performance. According to Ramos and De Melo, to encourage the linkage between military activities and the environment requires extensive research into techniques of developing, measuring and promoting the integration of environmental concerns at all levels of the military organisation, through to decision-making, logistics and operational practices.<sup>68</sup> Furthermore, there are environmental benefits, such as the minimisation of environmental impacts and improved employee environmental awareness. Compliance with legal environmental requirements cannot be achieved if the top management of the defence is not committed and willing to plan properly for environmental management.<sup>69</sup> Improvement in the environmental performance of the organisation requires that top management recognises that internal commitment at all levels of the organisation is imperative.<sup>70</sup>

This tool creates opportunities to communicate environmental matters with other state departments and related stakeholders for the benefit of the environment, in military-used land areas. However, the effectiveness of this performance indicator depends on whether the communication procedures for environmental management are well established and



known by every member of the defence force at any installation, as well as stakeholders outside the defence sector. Examples of these procedures are the process of receiving and responding to environmental concerns, consideration of the environmental concerns raised and communication of the results from audits and review processes, and so on. Furthermore, this is a mechanism that can be used by the top management of the defence to communicate policies, plans and programmes to military installations on an ad hoc basis.<sup>71</sup> However, Puvanasvaran et al. argue that the ad hoc approach offers little opportunity for improvement of environmental performance and efficiency.<sup>72</sup> Thus, inappropriate policies and constrained communication may lead to poor environmental management practices.<sup>73</sup>

### *Annual Environmental Reporting*

The annual environmental report is important with respect to the appraisal of environmental impact management in the defence force. In the SANDF, it is carried out in the form of a questionnaire, with questions covering a wide range of environmental management issues. These issues constitute matters such as natural and cultural resources, waste management, environmental education and awareness, military integrated environmental management programmes and so on. It is believed that the annual report will empower and enable the commanding officer to determine the level or extent of compliance in the military installation. Therefore, each military installation is expected to produce this compulsory annual environmental report. Regrettably, at GMI, no such reports are available, even though environmental reporting is compulsory. Accurate environmental reporting improves the integrity of the audit process.<sup>74</sup>

Adequate and accurate reporting guarantees the tracking of improvements in the environmental management process.<sup>75</sup> In addition, the monitoring of adequate implementation of the Environmental Management Plan (EMP) of the military exercise creates opportunities for additional measures for impacts to be developed, that are not provided for in the initial plan.<sup>76</sup> Environmental reporting in the defence should be used to communicate improvements and weaknesses in the environmental management programme. Chen et al. argue that environmental reporting creates an opportunity for constant assessment of the organisation's environmental practices and performance.<sup>77</sup> It also has the potential to improve stakeholders' relationships with the defence as an organisation.<sup>78</sup> Environmental reporting can have other benefits, such as the development of a database for all the environmental programmes of the defence.<sup>79</sup>

Most of the environmental reports that were analysed in this study, which were reports prepared for various exercises at SAACTC, have shown appropriate environmental management practices but also exposed significant weaknesses in the process. The

weaknesses noted include inconsistencies in the reporting practice (records are not continuous, i.e. there are gaps), inadequate reporting (many questions are left unanswered) and the lack of a sustainable reporting framework (the GMI being the case in point). Environmental reporting at the SAACTC is not as weak as it is at GMI, even though the Environmental Security Working Group (ESWG) [2006] provides a template for the annual environmental report of the defence.

The lack of environmental reporting at GMI indicates a lack of coercive factors at this military installation. Madi et al. outline coercive factors such as: no penalty for defaulting/non-compliance, no directive from the authority, no pressure from stakeholders and the lack of political influence.<sup>80</sup> Adopting Madi et al.'s framework for impediments of EMS implementation, it can also be argued that, at GMI, firstly, there is a lack of normative factors, which includes the lack of specific training and knowledge on the defence environmental management monitoring tools. Secondly, the lack of knowledge sharing with people outside the GMI, means there is no interaction with environmental experts and practitioners. Thirdly, it is the lack of involvement of the installation's top management personnel in its environmental management activities. Finally, the situation at GMI may also be indicative of the absence of an effective environmental communication system.

### *Environmental baseline and site closure reports*

It has been noted that, at SAACTC, the previous environmental report becomes the Environmental Baseline Report (EBR) for the subsequent training exercise. This approach seems to lack sufficient accuracy, especially if the next training exercise will be carried out after a long time. The most appropriate way to do this is to have an environmental conditions report (or site closure report) prepared after the training exercise so that the impacts can be adequately measured.<sup>81</sup> Nonetheless, under-staffing might be one of the major obstacles to adequate application of the environmental management tools. The EBR is then used for comparison against the Site Closure Report (SCR), which details the state of the training range at the end of the training exercise.<sup>82</sup>

To ensure compliance with the EMP of a training exercise, Environmental Representatives (ERs) are selected per unit. The ERs give an environmental compliance report to the commanding officer at the end of the training exercise. These reports ought to state the challenges encountered in terms of compliance with the EMP, as well as the impacts for which the plan has not catered. The DEO is also expected to act on all the incidence reports and take the necessary steps in dealing with each incident reported. Incidences may include fuel spillages, unexploded ordnances and the existence of any other hazardous material that may have been left on the training range, including its exact location. It

is, therefore, argued that this practice may allow the DEO to develop a database on the reports. Similarly, the SCR is as critical a document as the EBR.<sup>83</sup> Therefore, it needs to be kept on record for future reference.

The NATO-CCMS report also emphasises efficient document control. It argues that the provision of information to the right people at the right time and place is imperative to successful environmental management in the defence.<sup>84</sup> Documents are also kept to demonstrate compliance with legal requirements, as they provide evidence of on-going progress made with regard to environmental management or EMS implementation.<sup>85</sup> Therefore, the environmental reporting procedure must be made clear to every defence force member. Thus, it is important for the military to have an Environmental Reporting Framework (ERF).<sup>86</sup> It can therefore be argued that the absence of an ERF is linked to the collapse, or withdrawal, of the EMS for the SANDF, as noted by Smit and Magagula.<sup>87</sup>

The inadequate or inaccurate reporting noted in the 2009 environmental closure report is one of the weaknesses that this study has noted. This report (i.e. the ECR of 2009) does not indicate that insufficient funding is one of the major challenges to executing environmental management duties more efficiently.<sup>88</sup> This gives the impression that the funding for environmental management is adequate or sufficient, when it is not. According to Hill and Wang, the availability of financial resources is a major driver for effective environmental management.<sup>89</sup> West argues that funding (budget) to execute the environmental management programme in the defence is a crucial factor.<sup>90</sup> Therefore, without financial support, efforts towards environmental protection and sustainability in the SANDF will remain elusive.

### *Environmental Auditing*

Environmental auditing (EA) is one of the mechanisms adopted by the DoDMV to monitor and evaluate the environmental performance of the SANDF. EA is a tool used to assess an organisation's performance in relation to environmental management expectations.<sup>91</sup> This tool is a critical component in a comprehensive approach to an environmental management system that aims to reduce the impact of the activities on the environment.<sup>92</sup> According to Cook et al., EA has become an important policy instrument used to assess and improve the performance of the environmental programme of the organisation.<sup>93</sup>

Therefore, it is through audits that incidences of non-compliance can be identified. Once such cases have been identified (well documented in the EA report/findings), corrective measures ought to be implemented. The DEAT argues that, since its inception,

environmental auditing has proved to be a treasured tool in the management and monitoring of environmental and sustainable development programmes.<sup>94</sup> This is precisely because EA identifies potential environmental risks and further contributes towards finding corrective measures to specific environmental problems.<sup>95</sup>

According to the Environmental Implementation Plans (EIPs), the auditing and monitoring of the implementation of all measures for environmental management in the SANDF, as well as the monitoring of environmental performance and compliance with the relevant legislation, will be carried out at three levels. The levels are identified as follows:<sup>96</sup>

- *Environmental management systems audit:* the EMS for the defence should be continually audited by qualified personnel. Internally, the SANDF still lacks the necessary skills to carry out this task, however, internal capacity building in the DoDMV is reported to have begun in 1996. This would have continued to be expanded such that the department itself is able to carry out internal audits on environmental performance and compliance in the SANDF. The United Nations Development Programme (UNDP) recommends that in a case where there is a lack of qualified in-house auditor/s, the organisation can train some of its staff to become qualified environmental auditors.<sup>97</sup>

The implementation of the EMS for the SANDF is reported to have commenced in 2001. However, it has been established that the implementation of the defence EMS was terminated in 2007, due to a lack of progress.<sup>98</sup> Undoubtedly, this derailed the environmental management programme of the SANDF. The withdrawal of the EMS for the SANDF meant the end of the systematic identification of environmental impacts and the appropriate integration of environmental issues into the activities of the SANDF. The collapse of the EMS implementation in the SANDF can also be associated with the failure to integrate the management of the environment with the management of the entire defence force. Hens et al. argue that the successful implementation of EMS begins with the integration of environmental aspects in the management of the entire organisation.<sup>99</sup>

Without EMS in place, environmental management practices and programmes would not be adequately focused and coordinated. It must be recognised that EMS ensures that a systematic plan/approach is adopted to reduce environmental impacts, implement appropriate actions, as well as to coordinate and monitor environmental management activities.<sup>100</sup> EMS is an endless cycle of continuous planning, implementing, reviewing and improving the processes and instruments used to achieve the environmental management objectives.<sup>101</sup> Thus, the absence of this environmental management 'roadmap' indicates that almost every action and plan is bound to be less effective with respect to compliance improvement and sustainability.

Lillah and Struwig argue that EMS is a formalised, coordinated process that aims to assist an organisation to address its environmental impacts through policy development and implementation, resource and responsibility allocation, as well as the continual improvement of practices and performances based on monitoring and evaluation

processes.<sup>102</sup> Therefore, it is regrettable that the SANDF has not re-introduced the implementation of its EMS to guide its environmental management operations.

- **Internal audit:** this is to be carried out by the Defence Inspectorate. According to the Environmental Implementation Plan (EIP), instruments to perform the function of assessing compliance are still being developed so as to audit the implementation of environmental management in the SANDF.<sup>103</sup> This does not reflect well on the SANDF, given the period that has lapsed since its participation in the NATO-CCMS pilot study that was carried out from 1996-1999. Also, the DoDMV has been in a bi-national partnership with the USA DoD on military and environmental stewardship since 1997. Moreover, this drawback could be equated to the absence of EMS, which collapsed in 2007. Certainly, this confirms Lillah and Struwig's argument that an environmental management system is a framework, structure, or system that can be used to operationalise environmental management within an organisation.<sup>104</sup>
- **External audit:** internal audits are enhanced by getting an outside perspective, which is likely to be more objective.<sup>105</sup> The external audit of the SANDF is carried out by the Office of the Auditor-General. Even though this is an audit of the implementation of environmental management, it relates to the financial spending of the defence. Such audits are to be carried out in three-year cycles. According to Viegas et al., an external audit is driven by external factors that affect the organisation. These include the costs of enforcement and compliance, as well as incentives to promote proactive environmental management initiatives.<sup>106</sup> Proactive environmental management principles suggest that regular internal and external audits are best practices for improving the environmental operations of the organisation.<sup>107</sup>

According to the EIP, the environment management spending of the SANDF is integrated into the general expenditure of the defence, thus obscuring the actual environmental expenditure of the DoDMV.<sup>108</sup> Therefore, it is understandable that the external EA must be carried out by the Office of the Auditor-General. In this way, the defence may know exactly how much of its budget is spent on environmental management programmes. Furthermore, it will provide the SANDF with an outside view of their level of compliance with policy and other legal requirements.

However, in the final analysis, the final environmental audit report should communicate/indicate the areas for environmental improvements to the organisation and its employees.<sup>109</sup> Actions must be taken to address all the weaknesses and shortfalls that the audit process has indicated.

The practices at SAACTC regarding the monitoring of the implementation of environmental management indicates partial commitment to the effective management and protection of the environment from military activities. Thus, the SANDF needs to ensure that its activities adequately integrate environmental management practices, as

many other defence organisations are doing or have done so.<sup>110</sup> For example, the defence forces of countries of Australia, Canada, Portugal, Spain, Sweden, the United Kingdom and the United States of America have long understood the role of environmental management in peacetime activities.<sup>111</sup> Moreover, environmental management may prove critical in land used primarily to support field training requirements for combat readiness.<sup>112</sup> This is vital because effective military training requires a natural landscape with the appropriate features.<sup>113</sup> For this reason, military training areas are established in different geographical areas and are used for different military training purposes.<sup>114</sup>

### *Environmental Review Forum*

The Environmental Review Forum was intended to execute the function of reviewing the SANDF's environmental performance, as well as updating and improving the EMS for defence. Originally, this forum was formed to design and develop the EMS for the defence. Thereafter, the forum would have focused on assessing the environmental performance of the defence. Unfortunately, this forum was dissolved in 2009, two years after the termination of the pilot study on EMS implementation. The dissolution of this forum could mean that it failed to produce the desired outcomes. The primary objectives of the forum were to design and develop an applicable EMS for the defence, thereafter review its implementation and further ensure its continuous improvement. This instrument would have been retained for many years, until such time that the SANDF has sufficient capacity and capabilities to address environmental issues.

Furthermore, this mechanism would have been used as a major strategic platform to involve academics, environmental practitioners, as well as environmental experts as the Australian Defence Force has done.<sup>115</sup> The Australian Defence Force has a collaborative environmental management programme with state and local government agencies, universities, research institutions, neighbouring land owners and so on.<sup>116</sup> This is meant to ensure that the defence is always informed of cutting-edge information and developments in the field of environmental management. Dos Santos and Jabbour argue that constant reviews and improvement are essential for continuous, adequate and effective environmental management.<sup>117</sup> This is directly related to external linkages through which the DEO get to know of the latest developments in the field of environmental management.<sup>118</sup>

### *Steering Groups, Working Groups and Advisory Forums*

This mechanism is reported to be constituted of agents that would oversee the implementation and monitoring of the environmental performance of the SANDF. However, the agents to exercise the oversight function in the implementation and

monitoring environmental practice of the SANDF are not specified. Obviously, the core of the steering, working groups and the advisory forums on environmental implementation and monitoring should be formed by all the Senior Staff Officers – Environmental Services of the SANDF. These are the highly qualified environmental personnel of the DoDMV; as such, they inspect environmental practices in their respective regions. Advice can also be sought from some North Atlantic Treaty Organisation (NATO) member countries.

### *Environmental Awards Programme*

The environmental monitoring mechanism of the Defence (DoDMV) includes an environmental awards programme. This programme is commended in that it recognises the efforts and initiatives of individuals based in different installations and groups of individuals, towards environmental management and sustainability. According to Nee, organisations that incorporate rewards for environmental improvement, especially in their performance evaluation system, can expect a greater level of environmental management implementation practices.<sup>119</sup> This approach causes members of the defence force to see themselves as making a significant contribution to the management of the environment and to the environmental management programme of the defence.

Earnhart and Leonard emphasise the importance of this approach towards promoting environmental management in an organisation,<sup>120</sup> thus, it is one of the key approaches to the improvement of the defence force's environmental management profile. In addition, Lillah and Struwig also attest that, in many instances, employees are the initiators of environmental practices; therefore, recognition of their efforts will boost their morale and encourage them to achieve the highest standards of environmental protection.<sup>121</sup> Thus, through the environmental awards programme, senior environmental managers in the SANDF can identify individuals who should be recruited and trained to become additional environmental officers, in order to bridge the skills capacity gap that currently exists in the SANDF.

According to Matuszak-Flejszman, employees must be trained and acquire skills that are critical to the fulfilment of their environmental responsibilities and to achieve the environmental goals set by the organisation.<sup>122</sup> However, a career path in environmental management in the defence is viewed by the respondents as a “dead-end” and, thus, less attractive. Therefore, to change this perception, the DoDMV must rebrand the environmental management career path in the SANDF. One way of doing this, could be to conscript the military environmental management career into the ranks of the defence force. It is only then that defence force members will be interested in and attracted to this career in the defence force. It should also be noted that individuals are attracted to



institutions/divisions where there are fewer problems and where all the required facilities and resources are available or made available when needed. Furthermore, opportunities for growth and upward progression or mobility within the ranks of the military organisation will also act as a pulling factor.

In both military installations studied in this research, the communication of environmental management issues is flawed. This can be attributed to the collapse of EMS, as it serves as a beacon for environmental practice in any organisation. The GMI's situation is worse because there was no one (as of July 2011) leading its environmental management process. West states that, for the defence to succeed in its quest to ensure environmental protection and compliance with the applicable laws of the country, it ought to have adequate personnel to coordinate environmental management programmes for the defence.<sup>123</sup> Without such personnel, the whole system/plan will collapse, as has happened in the SANDF, especially where the EMS implementation was piloted. Lillah and Struwig state that the lack of resources and organisational structure (capital resources) are major obstacles in the successful implementation of EMS.<sup>124</sup> Certainly, the implementation of EMS and the achievement of its objectives is always threatened by low commitment to environmental tasks and insufficient staff.<sup>125</sup>

Wang and Wu rightly point out that the successful implementation of the EMS can be attributed to the internal and external factors of the organisation.<sup>126</sup> These are its characteristics: management attitude, culture, policies and stakeholder participation. The characteristics of the organisation consist of its diversity, size, private or public sector, profit making or non-profit making and functions. The defence is a highly diverse organisation, normally huge in size and a somewhat discrete public entity. It is a non-profit-making institution and its main function is to defend and protect the sovereignty and interests of the country.<sup>127</sup> All these pose serious challenges towards EMS implementation. Therefore, to adequately execute its main function, the defence has greater potential to harm the environment.<sup>128</sup> This is especially true in the absence of an effective environmental management programme or practices.

Stakeholder participation is profoundly linked to the external relationship of the defence with other state organs or the private sector. Stakeholders also include local communities and environmental groups. From this point of view, the SANDF is expected to have a positive environmental management attitude through the provision of all the necessary resources. The defence culture ought to be flexible enough to allow for the incorporation of environmental considerations into planning and military training.

## Extrapolation

Case studies are research methods that have theoretical implications extending beyond the particular area being studied.<sup>129</sup> This is true, though case studies are constricted, but are deep and rigorous in the interrogation of the issues of interest.<sup>130</sup> Thus, it is possible to extrapolate the results of the case study to understand or gain an insight into the environmental practices in other military installations of the SANDF having similar characteristics as the area investigated. Wikfeldt points out that case studies create opportunities to learn from one case and eventually understand many cases.<sup>131</sup> This becomes relatively easier in situations where the drivers or parameters and processes directly influencing those of the area not studied are also alike. It is therefore logical that similar results can be obtained from such areas.<sup>132</sup> Therefore, the results of the current study are a mirror image of environmental management practices in many other SANDF military installations that share the same characteristics (i.e. availability of all the necessary resources for good environmental management and/or lack thereof) as the two studied installations. This is what Gheondea-Elao referred to as making a broad conclusion based on one particular case; in other words making an inference about the unstudied case/s based on the observed case.<sup>133</sup> Also, the system resonance suggests that problems, processes and practices that share similar characteristics in different areas often yield comparable results.<sup>134</sup>

## Conclusion

The mechanisms adopted by the DoDMV to monitor and evaluate the implementation of environmental management in the SANDF are also used in the public sector for the purpose of measuring compliance with legal requirements. These are the same tools used in the private sector to assess their environmental management performance. However, the current study has established that there is a lack of adequate application of the environmental management monitoring tools, especially at GMI. The absence of environmental management monitoring at GMI is attributed to multiple factors. These include:

- the absence of skilled environmental personnel to lead the process and programme;
- a lack of knowledge of environmental monitoring mechanisms;
- the isolation of environmental management from the managerial processes of the defence as a unit; and
- a lack of commitment from top DoDMV officials to environmental management.

The latter two points are also applicable to the SAACTC, where there is also insufficient provisioning of basic resources towards improving the SANDF's environmental management profile. West indicates that environmental coordinators at military

installations must be trained to adequately perform their duties.<sup>135</sup> Environmental training will foster a pro-active attitude towards the protection of the natural environment and ensure sustainability of military training areas.<sup>136</sup> Moreover, the successful implementation of environmental management tools depends on the integration of environmental goals and objectives into the entire military management chain of command. Ramos and De Melo, as well as Hens et al. argue that environmental management practices must be integrated into the overall defence management chain in order to support military personnel tasked with overseeing environmental management issues on their respective installations.<sup>137</sup> Furthermore, Zentelis et al. argue that the integration of environmental issues into the management plans prevent the often committed mistake of treating environmental issues as an “after-thought”.<sup>138</sup> This becomes a major drawback to all environmental management efforts. Sometimes the “after-thought” approach to environmental management is as a result of lack of the resources required to adequately incorporate environmental consideration at the planning stage. It could also be the consequence of the lack of commitment to environmental monitoring, thus leading to the escalation of otherwise avoidable military environmental impacts.

At SAACTC, however, the current study noted a limited application of the environmental management monitoring mechanisms. Efforts to integrate environmental issues into military activities were also noted. These attempts to monitor environmental performance at SAACTC are laudable endeavours to improve the environmental management profile of the SANDF. Although ECRs are written, these reports are however not prepared as explained in the ESWG guidebook on environmental considerations during military operations, which was drafted for use by the SANDF. The failure to re-implement the EMS for the defence would lead to a complete collapse of the consideration or integration of environmental concerns to the activities of the SANDF, thereby rendering the MIEM approach less effective. Some of the mechanisms used in the SANDF to monitor the implementation of environmental management can inculcate the participatory principle of environmental management in personnel in the defence (an ideal situation).

In most cases, according to Seva and Jagers, environmental management and policy implementation are directed and/or influenced by either top-down, market-based or participatory ideals.<sup>139</sup> Given the defence culture, the top-down approach is part of the military doctrine. It is envisaged that, in the defence force, the top-down and participatory approaches can be combined to yield the desired outcomes. This does not exclude the possibility of adopting all three approaches to be used in the defence force, depending on the environmental problem at hand.<sup>140</sup> The success of any approach that is adopted hinges on the provision of all the basic resources for adequate environmental management.

The broader conclusion which can be drawn from the results of this study is that the environmental management practices noted in these two military installations are highly likely to be detected in many other installations of the SANDF. This inference is based on the fact that the main role players and processes are the same, thus the challenges are also similar because there is no formal system that guides the environmental management practices of the defence force.

## ENDNOTES AND REFERENCES

1. Rao, N.H. 2005. Environmental management: relevance and implications for management of defence installations for sustainability. *Current Science*, 88(11):1753-1758.
2. Smit, H.A.P. 2009. Shaping the environmental attitude of military Geography students at the South African Military Academy. *Journal of Geography in Higher Education*, 33(2):225-240. <https://doi.org/10.1080/03098260802276805>
3. Wang, X.H. & Wu, W. 2013. A review of environmental management systems in global defence sectors. *American Journal of Environmental Science*, 9(2):164-181. <https://doi.org/10.3844/ajessp.2013.164.181>
4. Zentelis, R.; Lindenmayer, D.; Roberts, J.D. & Dovers, S. 2017. Principles for integrated environmental management of military training areas. *Land Use Policy*, 62:86-195. <https://doi.org/10.1016/j.landusepol.2017.01.025>
5. Magagula, B. 2014. The environmental management system of the South African National Defence Force at the Grahamstown military installation. *Scientia Miliaria – South African Journal of Military Studies*, 2:143-163.
6. Ramos, T.B. & De Melo, J.J. 2005. Environmental management practices in the defence sector: assessment of the Portuguese military's environmental profile. *Journal of Cleaner Production*, 13:1117-1130. <https://doi.org/10.1016/j.jclepro.2004.05.003>  
 Ramos, T.B. & De Melo, J.J. 2006. Developing and implementing an environmental performance index for the Portuguese military. *Business Strategy and the Environment*, 15:71-86. <https://doi.org/10.1002/bse.440>  
 Rao, 2005, op. cit.;  
 Ramos, T.B.; Alves, I.; Subtil, R. & De Melo, J.J. 2007. Environmental performance policy indicators for the public sector: the case of the defence sector. *Journal of Environmental Management*, 82:410-432. <https://doi.org/10.1016/j.jenvman.2005.12.020>  
 Wang & Wu, 2013, op. cit.;  
 Oglanis, A.A. & Loizidou, M.D. 2017. Study of environmental management systems on defence. *Global Journal of Environmental Science and Management*, 3(1):103-120.
7. Sowman, M.; Fuggle, R.; & Preston, G. 1995. A review of the evolution of environmental evaluation procedures in South Africa. *Environmental Impact Assessment Review*, 15:45-67. [https://doi.org/10.1016/0195-9255\(94\)00004-K](https://doi.org/10.1016/0195-9255(94)00004-K)

8. North Atlantic Treaty Organisation, Committee on the Challenges of Modern Society (NATO-CCMS). 2000. *Pilot study on environmental management systems in the military sector*. Final Report. [Online]: <https://www.nato.int/science/publication/publi/envmil/envmil2.pdf> [Accessed 21 April 2009].
9. Campos, L.M.S. 2012. Environmental management systems (EMS) for small companies: a study in Southern Brazil. *Journal of Cleaner Production*, 32:141-148.  
<https://doi.org/10.1016/j.jclepro.2012.03.029>  
 Campos, L.M.S.; Heizen, D.A.M.; Verdinelli, M.A. & Miguel, P.A.C. 2015. Environmental performance indicators: a study on ISO 14001 certified companies. *Journal of Cleaner Production*, 99:286-296.  
<https://doi.org/10.1016/j.jclepro.2015.03.019>  
 Kudlak, R. 2017. Drivers of corporate environmentalism: The case of the Polish economy in transition. *Journal of Cleaner Production*, 142:3194-3203.<https://doi.org/10.1016/j.jclepro.2016.10.150>
10. Eltayeb, T.K. & Zailani, S. 2009. Going green through green supply chain initiatives towards environmental sustainability. *Operations and Supply Chain Management*, 2(2):93-110.
11. Caniato, F.; Caridi, M.; Crippa, L. & Moretto, A. 2012. Environmental sustainability in fashion supply chains: an exploratory case based research. *International Journal of Production Economics*, 135:659-670. <https://doi.org/10.1016/j.ijpe.2011.06.001>  
 Moldan, B.; Janoušková, S. & Hák, T. 2012. How to understand and measure environmental sustainability: indicators and targets. *Ecological Indicators*, 17:4-13.  
<https://doi.org/10.1016/j.ecolind.2011.04.033>
12. Du Pisani, J.A. & Sandham, L.A. 2006. Assessing the performance of SIA in the EIA context: a case study of South Africa. *Environmental Impact Assessment Review*, 26:707-724.  
<https://doi.org/10.1016/j.eiar.2006.07.002>  
 Morelli, J. 2011. Environmental sustainability: a definition for environmental professionals. *Journal of Environmental Sustainability*, 1(1):1-8. <https://doi.org/10.14448/jes.01.0002>  
 Soini, K. & Birkeland, I. 2014. Exploring the scientific discourse of cultural sustainability. *Geoforum*, 51:213-223. <https://doi.org/10.1016/j.geoforum.2013.12.001>
13. Soini & Birkeland, 2014, op. cit.;  
 Soini, K. & Dessein, J. 2016. Culture-sustainability relation: towards a conceptual framework. *Sustainability*, 8(167):1-12. <https://doi.org/10.3390/su8020167>
14. Rantala, M.; Hujala, T. & Kurttila, M. 2012. Measuring and monitoring socio-cultural sustainability in the action of forest biodiversity cooperation networks. *SilvaFennica*, 46(3):441-459.  
<https://doi.org/10.14214/sf.52>  
 Soini & Birkeland, 2014, op. cit.;  
 Soini & Dessein, 2016, op. cit.
15. Soini & Birkeland, 2014, op. cit.
16. NATO-CCMS, 2000, op. cit.
17. Rao, 2005, op. cit.
18. NATO-CCMS, 2000, op. cit.;  
 Ramos et al., 2007, op. cit.
19. NATO-CCMS, 2000, op. cit.
20. Ibid.

21. Dawson, M. 2004. Environmental management systems (EMS) in the military sector: promoting broader implementation. In: K. Mahutova, J.J. Barich, & R.A. Kreizenbeck (eds.), *Defense and the environment: Effective scientific communication*, Berlin: Kluwer. pp. 75-83.  
[https://doi.org/10.1007/1-4020-2084-8\\_9](https://doi.org/10.1007/1-4020-2084-8_9)
22. Wang & Wu, 2013, op. cit.
23. Rao, 2005, op. cit.
24. NATO-CCMS, 2000, op. cit.;  
Ramos & De Melo, 2005, op. cit.;  
Ramos & De Melo, 2006, op. cit.;  
Wang & Wu, 2013, op. cit.
25. Wang & Wu, 2013, op. cit.
26. Ramos & De Melo, 2005, op. cit.
27. Ibid.
28. Whitford, A.B. & Wong, K. 2009. Political and social foundations for environmental sustainability. *Political Research Quarterly*, 62(1):190-204. <https://doi.org/10.1177/1065912908318322>
29. Rao, 2005, op. cit.
30. Prebilič, V. & Ober, K. 2005. Defence system and ecology. The North Atlantic Treaty Organization role. *Polemos* 8(1-2):183-203.
31. Babcock, H.M. 2007. National security and environmental laws: a clear and present danger. *Virginia Environmental Law Journal*, 25:105-156.
32. Prebilič & Ober, 2005, op. cit.
33. NATO/SPS. 2015. Environmental aspects of military compounds (Phase II). *The NATO Science for Peace and Security Programme*. [Online]: [https://www.nato.int/science/topical\\_ws/eamc/Compounds\\_Workshop\\_1&2-summary\\_report.pdf](https://www.nato.int/science/topical_ws/eamc/Compounds_Workshop_1&2-summary_report.pdf) [Accessed 16 September 2016].
34. Ramos & De Melo, 2005, op. cit.;  
Ramos & De Melo, 2006, op. cit.;  
Ramos et al., 2007, op. cit.;  
Smit, H.A.P. 2009. The development of an environmental approach in the South African Department of Defence. In: H. Häusler & R. Mang (eds.), *International Handbook Military Geography, 2. Proceedings of the 8<sup>th</sup> International Conference on Military Geosciences, 15-19 June*. Truppendienst-Handbook. 2011. *Arbeitsgemeinschaft Truppendienst*. Ministry of Defence and Sports, Vienna.;  
Wang & Wu, 2013, op. cit.
35. NATO/SPS. Environmental aspects of military compounds (Phase II). 2008. *The NATO science for peace and security programme*. Report No. 283. [Online]: [https://www.nato.int/science/topical\\_ws/eamc/283-final\\_report\\_Compounds\\_phasel.pdf](https://www.nato.int/science/topical_ws/eamc/283-final_report_Compounds_phasel.pdf) [Accessed 5 August 2015].

36. Environmental Security Working Group (ESWG). 2001. *Conversion of military bases in South Africa*. A joint South Africa – United States project under the auspices of the SA – USA environmental security working group, defence committee of the binational commission. Publication ESWG/001.
37. Environmental Security Working Group (ESWG). 2000. *Military Integrated Training Range Management Guidebook*. A joint project between the USA and SA Departments of Defence.
38. Environmental Security Working Group (ESWG). 2003. *Guidebook on development an implementation of environmental education and training in the military*. A joint United States – Republic of South Africa Environmental Security Working Group project.
39. Environmental Security Working Group (ESWG). 2005. *Guidebook on environmental impact assessment in the military*. A Joint United States – Republic of South Africa Environmental Security Working Group Project, United States – South Africa Defense committee. Publication ESWG/005. [Online]: <https://www.denix.osd.mil/denix/Public/Training/training.html#int> [Accessed 5 August 2015].
40. Finnish Defence Forces. 2008. *Environmental guidebook for military operations*. [Online]: <http://www.prakl.fi/en> [Accessed 5 August 2015].
41. Smit, 2009, op. cit.
42. Ibid.;
43. Ibid.
44. Magagula, 2014, op. cit.
45. Carolan, C.M.; Farbat, L. & Smith, A. 2016. Developing the descarte model: the design of case study research in health care. *Qualitative Health Research*, 26(5):626-639. <https://doi.org/10.1177/1049732315602488>
46. Heale, R. & Twycross, A. 2018. What is a case study? *Evidence Based Nursing*, 21(1):7-8. <https://doi.org/10.1136/eb-2017-102845>
47. Gray, D.E. 2004. *Doing research in the real world*. UK: SAGE.
48. Ibid.
49. Félix-Medina, M.H. & Monjardin, P.E. 2009. Link-tracing sampling with an initial sequential sample of sites: Estimating the size of a hidden human population. *Statistical Methodology*, 6:490-502. <https://doi.org/10.1016/j.stamet.2009.04.004>
50. Sheng, M.L.; Hsu, C. & Wu, C. 2011. The asymmetric effect of online social networking attribute-level performance. *Industrial Management & Data Systems*, 111(7):1065-1086. <https://doi.org/10.1108/02635571111161299>
51. Duriau, V.J.; Reger, R.K. & Pfarrer, M.D. 2007. A content analysis of the content analysis literature in organization studies research themes, data sources, and methodological refinements. *Organizational Research Methods*, 10(1):5-34. <https://doi.org/10.1177/1094428106289252>
52. General Accounting Office (GAO). 1996. Content analysis: a methodology for structuring and analyzing written material. *Program Evaluation and Methodology Division*.
53. Krippendorff, K. 1989. Content analysis. In: E. Barnouw, G. Gerbner, W. Schramm, T.L. Worth & L. Gross (eds.), *International encyclopedia of communication*, 1:403-407. New York, NY: Oxford University Press. [Online]: [http://repository.upenn.edu/asc\\_papers/226](http://repository.upenn.edu/asc_papers/226) [Accessed 7 March 2015].



54. Elo, S. & Kyngäs, H. 2008. The qualitative content analysis process. *Journal of Advanced Nursing*, 62(1):107-115. <https://doi.org/10.1111/j.1365-2648.2007.04569.x>
55. Department of Defence. 2001 & 2008. *Environmental implementation plan for the Defence*. 1<sup>st</sup> and 2<sup>nd</sup> ed. Pretoria, South Africa.
56. Smith, C.P. 2000. Content analysis and narrative analysis. In: T. Reis & C. Judd (eds.), *Handbook of Research Methods in Social and Personality Psychology*. UK: Cambridge University Press. pp. 313-335.
57. Coffey & Atkinson, 1996.;  
Saunders, M.; Lewis, P. & Thornhill, A. 2003. *Research methods for business students*, 3<sup>rd</sup> ed. USA: Prentice-Hall.;  
Liamputtong, P. & Ezzy, D. 2005. *Quantitative research methods*, 2<sup>nd</sup> ed. UK: Oxford University Press.;  
Punch, K. 2005. *Introduction to social research: quantitative and qualitative approaches*, 2<sup>nd</sup> ed. Thousand Oaks, CA: SAGE.
58. Smit, 2009, op. cit.
59. Ramos & De Melo, 2005, op. cit.
60. Ramos et al., 2007, op. cit.
61. Ibid.
62. United States Marine Corps. *Commander's Guide to Environmental Management*. 2009. [Online]: <https://bit.ly/2JDPjd7> [Accessed 5 August 2015].
63. Ibid.
64. Ramos & De Melo, 2006. op. cit.
65. Ramos et al., 2007, op. cit.
66. Neves, F.O.; Salgado, E.G. & Beijo, L.A. 2017. Analysis of the environmental management system based on ISO 14001 on the American continent. *Journal of Environmental Management*, 199:251-262. <https://doi.org/10.1016/j.jenvman.2017.05.049>
67. Hens, L.; Wiedemann, T.; Raath, S.; Stone, R.; Renders, P.; Craenhals, E. & Richter, B. 2010. Monitoring environmental management at primary schools in South Africa. *Journal of Cleaner Production*, 18:666-677. <https://doi.org/10.1016/j.jclepro.2009.11.001>
68. Ramos & De Melo, 2005, op. cit.
69. Oliveira, J.A.; Oliveira, O.J.; Ometto, A.R.; Ferraud, A.S. & Salgado, M.H. 2016. Environmental management system ISO 14001 factors for promoting the adoption of cleaner production practices. *Journal of Cleaner Production*, 133:1384-1394. <https://doi.org/10.1016/j.jclepro.2016.06.013>
70. Testa, F.; Rizzi, F.; Daddi, T.; Gusmerotti, N.M.; Frey, M. & Iraldo, F. 2014. EMAS and ISO 14001: the differences in effectively improving environmental performance. *Journal of Cleaner Production*, 68:165-173. <https://doi.org/10.1016/j.jclepro.2013.12.061>
71. Dos Santos, J.B. & Jabbour, C.J.C. 2013. Critical factors to be considered when planning the implementation of environmental improvements and energy saving. *Journal of Energy in Southern Africa*, 24(4):22-29.

72. Puvanasvaran, A.P.; Muhamad, M.R. & Kerk, R.S.T. 2010. A review of purpose, benefits, impediments and structure of environmental management system (EMS). *Australian Journal of Basic and Applied Sciences*, 4(10):4710-4716.
73. De Joussineau, H. 2013. Obstacles when facing ISO 14001 EMS implementation for organizations in developing countries. A case study about Stora, Enso's agro-forestry project in Lao People's Democratic Republic. Master's thesis, Stockholm University.
74. Cook, W.; Van Bommel, S. & Turnhout, E. 2016. Inside environmental auditing: effectiveness, objectivity, and transparency. *Current Opinion in Environmental Sustainability*, 18:33-39. <https://doi.org/10.1016/j.cosust.2015.07.016>
75. Department of Environmental Affairs & Tourism (DEAT). 2004. Overview of integrated environmental management, *Integrated Environmental Management, Information Series 0*, Department of Environmental Affairs & Tourism. Pretoria.
76. Environmental Security Working Group (ESWG). 2006. *Guidebook on environmental considerations during military operations*. A joint United States – Republic of South Africa environmental security working group project. Publication ESWG/006.
77. Chen, P.H.; Ong, C.F. & Hsu, S.C. 2016. Understanding the relationships between environmental management practices and financial performances of multinational construction firms. *Journal of Cleaner Production*, 139:750-760. <https://doi.org/10.1016/j.jclepro.2016.08.109>
78. Ramos et al., 2007 op. cit.;  
Royal Government of Bhutan – National environment commission.2011. Environmental management tools and techniques: a learning material. [Online]: <https://bit.ly/2U92e4a> [Accessed 16 September 2015].
79. Rao, 2005, op. cit.
80. Madi, N.; Joseph, C. & Rahmat, M. 2017. Impediments of environmental management system (EMS) implementation in Malaysian local authorities – preliminary findings. *SHS Web of Conferences*, 34:1-7. <https://doi.org/10.1051/shsconf/20173405001>
81. Environmental Security Working Group (ESWG), 2006, op. cit.
82. Chartier, R.J. 2003. Environmental issues associated with operation Enduring Freedom. *Engineer*. 24-27.
83. Ibid.
84. NATO-CCMS, 2000, op. cit.
85. Ibid.;  
Department of Environmental Affairs & Tourism (DEAT), 2004, op. cit.
86. Wu, W. & Wang, X.H. 2011. Development of an environmental performance indicator framework to evaluate an environmental management system for Shoalwater Bay Training Area, Queensland, Australia. *Labour Management Development*, 1:1-26.
87. Smit, 2009, op. cit.;  
Magagula, 2014, op. cit.
88. Department of Defence, 2001 & 2008, op. cit.;  
Magagula, 2014, op. cit.
89. Hill, R.C. 2000. Integrated environmental management systems in the implementation of projects. *South African Journal of Science*, 96:50-54.;

- Wang, X. 2011. Exploring trends, sources, and causes of environmental funding: A study of Florida counties. *Journal of Environmental Management*, 92:2930-2938.  
<https://doi.org/10.1016/j.jenvman.2011.07.002>
90. West, T.D. 1997. Environmental quality: environmental protection and enhancement. Army Regulation 200-1. *Department of the Army Washington, DC*. AR 200-1:1-43.
  91. Royal Government of Bhutan – National environment commission, 2011, op. cit.
  92. Goodall, B. 1995. Environmental auditing: a tool for assessing the environmental performance of tourism firms. *The Geographical Journal*, 161(1):29-37. <https://doi.org/10.2307/3059925>
  - Viegas, C.V.; Bond, A.; Ribeiro, J.L.D. & Selig, P.M. 2013. A review of environmental monitoring and auditing in the context of risk: unveiling the extent of a confused relationship. *Journal of Cleaner Production*, 47:165-173. <https://doi.org/10.1016/j.jclepro.2012.12.041>
  93. Cook, et al., 2016, op. cit.
  94. Department of Environmental Affairs & Tourism (DEAT). 2004, op. cit.
  95. Environmental Security Working Group (ESWG). 2005. *Guidebook on Environmental Impact Assessment in the Military*. A Joint United States – Republic of South Africa Environmental Security Working Group Project United States – South Africa Defense Committee. Publication ESWG/005. [Online]: <https://www.denix.osd.mil/denix/Public/Training/training.html#int> [Accessed 5 August 2015].
  96. Department of Defence, 2001 & 2008, op. cit.
  97. Royal Government of Bhutan – National environment commission, 2011, op. cit.
  98. Smit, H.A.P. 2009. Shaping the environmental attitude of military geography students at the South African Military Academy, *Journal of Geography in Higher Education*, 33(2):225-240. <https://doi.org/10.1080/03098260802276805>
  99. Hens et al., 2010, op. cit.
  100. Famiyeh, S.; Kuttu, S. & Anarfo, E.B. 2014. Factors influencing the implementation of environmental management systems in Ghanaian firms. *Environmental Management and Sustainable Development*, 3(2):18-30. <https://doi.org/10.5296/emsd.v3i2.5893>
  101. Ibid.
  102. Lillah, R. & Struwig, M. 2016. Factors influencing business implementation of environmental management systems. *Journal of Economics, Business and Management*, 4(4):272-279. <https://doi.org/10.18178/joebm.2016.4.4.403>
  103. Department of Defence, 2001 & 2008, op. cit.
  104. Lillah & Struwig, 2016, op. cit.
  105. Giles, F. 2008. Assessing the effectiveness of your environmental management system. *Environmental Quality Management*, 18(2):1-6.
  106. Viegas et al., 2013, op. cit.
  107. Giles, 2008, op. cit.
  108. Department of Defence, 2001 & 2008, op. cit.

109. Kaur, H. 2011. Impact of human resource factors on perceived environmental performance: an empirical analysis of a sample of ISO 14001 EMS companies in Malaysia. *Journal of Sustainable Development*, 4(1):211-224.
110. Ramos & De Melo, 2006, op. cit.
111. Ibid.;  
Ramos & De Melo, 2006, op. cit.
112. Ramos & De Melo, 2005, op. cit.
113. Ibid.
114. Zentelis et al., 2017, op. cit.
115. Bowett, J.; Davidson, A. & Danvers, T. 2015. Shoalwater Bay training area: capability, conservation and collaboration. *Innovation in Management*. pp. 142-147.  
[Online]: <http://www.defence.gov.au/environment/> [Accessed 7 August 2015].
116. Ibid.
117. Dos Santos & Jabbour, 2013, op. cit.
118. Magagula, 2014, op. cit.
119. Nee, G.Y. 2011. Determining factors for ISO 14001 EMS implementation among SMEs in Malaysia: A resource based view. *International Journal of Social, Behavioral, Education, Economic, Business and Industrial Engineering*, 5(11):1497-1502.
120. Earnhart, D. & Leonard, J.M. 2013. Determinants of environmental audit frequency: the role of firm organizational structure. *Journal of Environmental Management*, 128:497-513.  
<https://doi.org/10.1016/j.jenvman.2013.05.042>
121. Lillah, & Struwig, 2016, op. cit.
122. Mastuszak-Flejszman, A. 2011. Factors for improving environmental management systems in Polish companies accordingly to ISO 14001. *Polish Journal of Environmental Studies*, 20(3):709-718.
123. West, 1997, op. cit.
124. Lillah & Struwig, 2016, op. cit.
125. Le, X.Q.; Vu, V.H.; Hens, L. & Heur, B.V. 2014. Stakeholder perceptions and involvement in the implementation of EMS in ports in Vietnam and Cambodia. *Journal of Cleaner Production*, 64:173-193. <https://doi.org/10.1016/j.jclepro.2013.07.032>
126. Wang & Wu, 2013, op. cit.
127. Ramos et al., 2007, op. cit.
128. Ibid.
129. Steinberg, P.F. 2015. Can we generalize from case studies? *Global Environmental Politics*, 15(3):152-175
130. Ibid.
131. Wikfeldt, E.S. Case study inference: Four generalisation methods and how they may be integrated. [Online]: <http://www.diva-portal.org/smash/get/diva2:1062648/fulltext01.pdf> [Accessed 30 July 2018].
132. Steinberg, 2015, op. cit.

133. Gheondea-Elao, A. 2014. Is qualitative research generalizable? *Journal of Community Positive Practices*, 14(3):114-124.
134. Steinberg, 2015, op. cit.
135. West, 1997, op. cit.
136. Massoud, J.A.; Daily, B.F. & Bishop, J.W. 2011. Perceptions of environmental management systems: an examination of the Mexican manufacturing sector. *Industrial Management & Data Systems*, 111(1):5-19. <https://doi.org/10.1108/02635571111099703>
137. Ramos & De Melo, 2005, op. cit.;  
Ramos & De Melo, 2006, op. cit.;  
Hens et al., 2010, op. cit.
138. Zentelis et al., 2017, op. cit.
139. Seva, M. & Jagers, S.C. 2013. Inspecting environmental management from within: the role of street-level bureaucrats in environmental policy implementation. *Journal of Environmental Management*, 128:1060-1070. <https://doi.org/10.1016/j.jenvman.2013.06.038>
140. Ibid.

# Spatial Decision Support

## FOR MILITARY INTEGRATED ENVIRONMENTAL MANAGEMENT IN SOUTH AFRICA



# 4

Jan Marx & Hannes van der Merwe 

### Introduction

The research reported here is extracted from doctoral research,<sup>1</sup> conducted on a Military Training Area (MTA) of the SANDF. It represents timeous response to growing international and national concern about the environmental impacts of normal military activity on the extensive terrains under military command. This concern has been on the rise over the past quarter century as national governments worldwide commenced with implementation of stringent legislation related to environmental management. The research endeavoured to build an understanding of military impacts and to design information-based management procedures for implementation by the military. Methodologically the research commenced with meticulous field recording of impact evidence of military activity on a military terrain located in an ecologically sensitive environment and exposed to a wide range of high-impact activities. The research concluded with the design of a spatial database to support the application of a spatial decision support system based on geographical information system technology potentially applicable to most military terrains in South Africa and beyond.



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## Literature Review: Geographical Information System Application History in the Military

A search of the global literature identified a fairly limited, yet growing, range of sources, suggesting that perhaps the military is somewhat lagging in its adoption of the technology. Explanations to account for this state of affairs include:

1. The nature of military applications is clandestine and therefore not freely discussed or published in the public domain; and
2. military applications tend to be proprietary and less likely to have been developed on well-known commercial software platforms.<sup>2</sup>

Browsers, as employed here, are geared to pick up published scholarly products and not operational system discussions and confidential system reports. Recognising these constraints in the literature search, a number of general comments and conclusions are still justified.

A distinctive temporal and origin/location or national trend in the source origins can be discerned. While fairly specific or focused application issues emanated from Western countries earlier on, the first general texts dealing with geospatial application in the military surfaced fairly recently. Examples are Rehak,<sup>3</sup> Singer et al.<sup>4</sup> and Loechel, Mihelcic and Pickl<sup>5</sup> in Canada. The field has recently been introduced in South Africa.<sup>6</sup> The second trend is the apparent acceleration in 'open' source generation to the public domain from eastern countries, especially China, albeit more often dealing with rather specific application issues as demonstrated by several sources.<sup>7</sup> It seems safe to claim that Geographical Information System (GIS) adoption and the unchaining of its potential to military applications worldwide has entered a more prolific and overt development phase.

Of special interest to this research was the extent to which spatial multi-criteria analysis/assessment/evaluation using GIS in military applications has been reported. Themes include military land condition assessment,<sup>8</sup> roadside bomb detection in Afghanistan,<sup>9</sup> and environmental condition assessment<sup>10</sup> as examples of operational applications of this most sophisticated decision-support tool in various operational conditions.

It must further be noted that most sources encountered on GIS in the military had what is here termed operational military management applications as focus. General tactical and operational planning scenario building and command gaming provide new foci.<sup>11</sup> Transportation-related operational issues like marine navigation,<sup>12</sup> vehicle use patterns during field training,<sup>13</sup> operational surveillance and reconnaissance intelligence,<sup>14</sup>



transportation path planning<sup>15</sup> and full supply chain management<sup>16</sup> receive growing attention. Others deal with less specific issues like operations support specifically in desert environments,<sup>17</sup> enhancing situational awareness<sup>18</sup> and information system integration.<sup>19</sup>

The focus of this research has been on GIS in *military environmental management*, a discipline receiving much less attention when combining the search with geospatial technology application. Godschalk<sup>20</sup> is the definitive source on specifying how 'green soldiering' is to be achieved through MIEM application in the SANDF. Some sources encountered were much more specific in terms of analysing and handling environmental management goals such as land use and conservation assessments on (British) military lands,<sup>21</sup> while another<sup>22</sup> compared the environmental management system (EMS) strategies and policies for military activities in the American, Canadian, Brazilian and NATO armies.

An encouraging trend is detected in terms of how integrated operational/environmental military management is becoming a focus in a number of studies – exactly what this research aims to accomplish. DeFraites<sup>23</sup> offers insight from the military medical field into how to build operational situational awareness through simulation in geographic information systems and how this may be adopted for environmental applications. General directives<sup>24</sup> and specific applications like vehicle erosion tracking,<sup>25</sup> traffic dust impact<sup>26</sup> and general land condition assessment<sup>27</sup> offer useful management advice.

Of necessity a relatively large contingent of sources reported on technical GIS/system requirements and characteristics and analytical techniques – information of note to system operators. Authors reporting on the use of remote sensing,<sup>28</sup> on visibility analysis,<sup>29</sup> on system configuration,<sup>30</sup> on mapping language adaptation,<sup>31</sup> on terrain and soil analysis for trafficability<sup>32</sup> and on mobile geospatial information systems<sup>33</sup> delve deeper into the technologies.

In military environmental management the coverage of military activity impact assessment is important and several related sources were found. These included broad landscape risk<sup>34</sup> and narrow erosion risk<sup>35</sup> assessment. Insight into approaches towards the evaluation and assessment of military land conditions and the restoration of military-training areas is also proffered.<sup>36</sup>

Much emphasis in this literature domain deals with terrain/location analysis in GIS and these are well covered by the source base – as indicated above in various contexts. Published material<sup>37</sup> covers aspects from remote sensing application to sophisticated

terrain and visibility analysis from Digital Terrain Models (DTMs). These techniques are applied to the reconstruction of historical 'battlescapes'<sup>38</sup> and fortifications,<sup>39</sup> broadly in aid of military heritage conservation.<sup>40</sup>

Finally, it is important to note the suggestions and debates surrounding the need to drive the adoption of military GIS – its military application philosophy and system structure. Calls for the incorporation of systems in the general operational,<sup>41</sup> urban operational,<sup>42</sup> medical situational awareness enhancement,<sup>43</sup> peace-time operational site planning for waste management facilities,<sup>44</sup> storm surge and sea-level rise impact zones,<sup>45</sup> and, of course, military environmental management<sup>46</sup> domains emanate throughout – a call we support from the viewpoint of this research.<sup>47</sup>

## Geospatial Technologies for the Military

A range of technologies with spatial or locational awareness have been developed, chiefly for and by military expertise and to serve peculiar military needs. Military activity plays out in locations and deploys over spaces, making it ideally suited to Geographical Information Technology (GIT) application. The comprehensive geospatial technology of SDSS and GISs as a particular technology in SDSS and some GIS application examples in military context are overviewed first.

### *Spatial decision support systems*

SDSS are Decision Support Systems (DSS) with a spatial component to aid decision making when problems are ill-structured or semi-structured,<sup>48</sup> i.e. they cannot be solved with an algorithm or a predefined sequence of operations. Predictive analysis is often required to present decision makers with different scenarios to explore and understand the possible effects of their decisions. DSS are meant to support analysis in complex environments like the military. They require a database management system, analytical modelling capabilities, analysis procedures and a user interface with display and report generators. DSS often use expert systems (software programs) that mathematically analyse subject-specific knowledge in the form of context-specific rules to interpret and analyse data to solve problems.

SDSS should include a geographical database, mechanisms for spatial data input, representation of spatial relations and structures, spatial analysis functions and various output forms including maps.<sup>49</sup> GISs comprise many of the key features of an SDSS that handles spatial data. GIS and DSS can be combined, modified or customised to create SDSS.<sup>50</sup>

Because SDSS are designed for specific applications, like the military, many of the operations can be automated to perform typical or routine screening or modelling tasks. This reduces the need for user input and the possibility of error – which can be catastrophic in the military environment. Development and software costs are limited because large institutions like the military in South Africa are already licenced and run GIS in dedicated units, while open-source software is universally available.<sup>51</sup>

### *Geographical Information System technology*

To appreciate the inherent value of GIS adoption, basic knowledge about the technology and a grasp of the innovative application possibilities (like spatial modelling) is a requisite. This section imparts the technical basics on GIS and multi-criteria evaluation as one of its application modes practically employed further on. GISs are special computer systems for the capture, storage, query, analysis, modelling and display of geographically referenced (spatial) data.<sup>52</sup> Longley et al. defined spatial analysis as “the process by which we turn raw spatial data into useful information ... to add value, support decisions and reveal patterns and anomalies that are not immediately obvious”.<sup>53</sup>

Spatial analysis requires spatial database construction, fortunately no longer a constraint since state-owned data has become freely accessible to the public through legislation. Requisite (micro) computer systems are similarly ubiquitous, with Microsoft (MS) Windows the dominant operating platform. GIS professionals currently use either ArcView or ArcGIS developed by ESRI, while Autodesk, Intergraph and other GIS software developers compete for the remaining market share. Open-source software applications like QGIS are on the rise and growing in sophistication. Henrico<sup>54</sup> proved that units or directorates can successfully deploy Free and Open Source Software Geographic Information Systems (FOSSGIS) in order to expand the existing GIS capabilities for military operations. Most importantly, GIS operators, also called ‘brainware’,<sup>55</sup> who use and manage these systems are multiplying rapidly. To ensure that GIS users, including the military, use the technology appropriately, GIS applications are dedicated for specific tasks only, creating a SDSS.

### **Multi-criteria Spatial Analysis in Geographical Information Systems**

Two modes of GIS decision-support application are available. Simple cumulative Boolean overlaying provides ‘hard’ operational rules for the conduct of activities, while Multiple-Criteria Evaluation (MCE) allows more subtle suitability measurement along a sliding numerical scale of intensity/suitability/sensitivity. The two techniques are briefly referred to here, but for methodological clarity the reader is referred to Van der Merwe<sup>56</sup>

and the original source dissertation.<sup>57</sup> The discussion principally structures the actual procedural steps followed in this study and indicates participants in the decision-making process deemed ideal for their respective purposes. All technical and judgmental decisions were made by a consultative team of military participants.

Designing and implementing the geospatial modelling instrument introduced in this chapter required consideration of the hierarchical command and procedural framework within which environmental and operational plans and actions are derived in the SANDF. This 10-step process is graphically encapsulated in figure 4.1. The next section elaborates on the layers of command responsibility and how these affect the modelling options developed here.

## **Incorporating the Military Integrated Environmental Management Command Framework**

The establishment and maintenance of MIEM practices in the SANDF is a legally binding policy commitment that must be complied with. As the logical exponent of ensuring that ‘green soldiering’<sup>58</sup> becomes embedded in SANDF business conduct, this study aims to enhance environmental management and operational prerogatives in an integrated framework envisaged as operating in figure 4.1. The framework sketches the management responsibility structure from national command to base level and indicates the conceptual niche where the GIS-enabled management support system is to be implemented. The framework foresees as the *primary (first) driver* a commitment embedded at senior military command level, where policy (as in existing official MIEM commitment) is formulated, funding is earmarked and supervision/reporting is enforced. At this level legal/constitutional compliance with national legislation and international commitments are reconciled. Importantly, the uneasy relationship between environmental responsibility and operational efficiency and goal attainment is principally prioritised and cast in command directives. These directives take into consideration the specific imperatives made of particular operational environments and the local bases responsible for them. The end result of this ‘driver’ is a clear directive to each command post on the alignment between MIEM and operational imperatives to be acted upon by base commands.

As a consequence, at the *individual operational level*, the geospatial model requirements are driven by the technical military determinants and characteristics of the specific military activity executed, i.e. weaponry discharged, vehicular and other movement taking place and the subsequent environmental impacts of a given type and extent. Determining the impact falls within the domain of the military product-expert.

This functionary could be locally based, but could also be sourced nationally or even internationally, to ensure that a proper understanding of impacts is derived for incorporating and translating into the impact rule base of each particular activity type. Up to this point (steps 1-3) in the modelling framework, the model has national (i.e. all SANDF) relevance and implications. The model construction focus then (steps 4 and 5) moves to the *technical level of GIS construction* and tailoring the operation at the local base level. This requires close cooperation between the military expert and the GIS designer at base level. These functionaries have to formulate workable rule sets for ensuring that management and operational deployment prerogatives are captured in modelling format. Most importantly, the spatial data sets capturing the essence of the operational space (human, infrastructural, natural and operational) in a GIS database, as prerequisite for designing the geospatial modelling application, must be decided upon. The *GIS application process* executes steps 6-10 in figure 4.1 and entails the gathering and construction of the appropriate geospatial data in electronic map format. It includes both the importation of existing electronic data layers, digital conversion of existing maps and the employment of GIS functions to generate distance and buffering images. Also, some physical features may be manually digitised by heads-up or similar digitising exercises. The final data preparation step typically involves the conversion of the electronic data layers to standardised values reflecting some form of meaningful pronouncement on, for instance, sensitivity to impacts or suitability for various purposes.

Execution of the GIS model can follow one of two options, depending on the decision-making mode envisaged. Option choice hinges on whether some operational decisions need to be guided or whether best-practice alternatives need to be determined. The first mode is typically applied in operational decision-making and guidance of activity execution and is therefore based on 'hard' (Boolean) determinants. The second mode allows more subtle decisions to be made based on human judgement and weighted multiple criteria (MCE application).

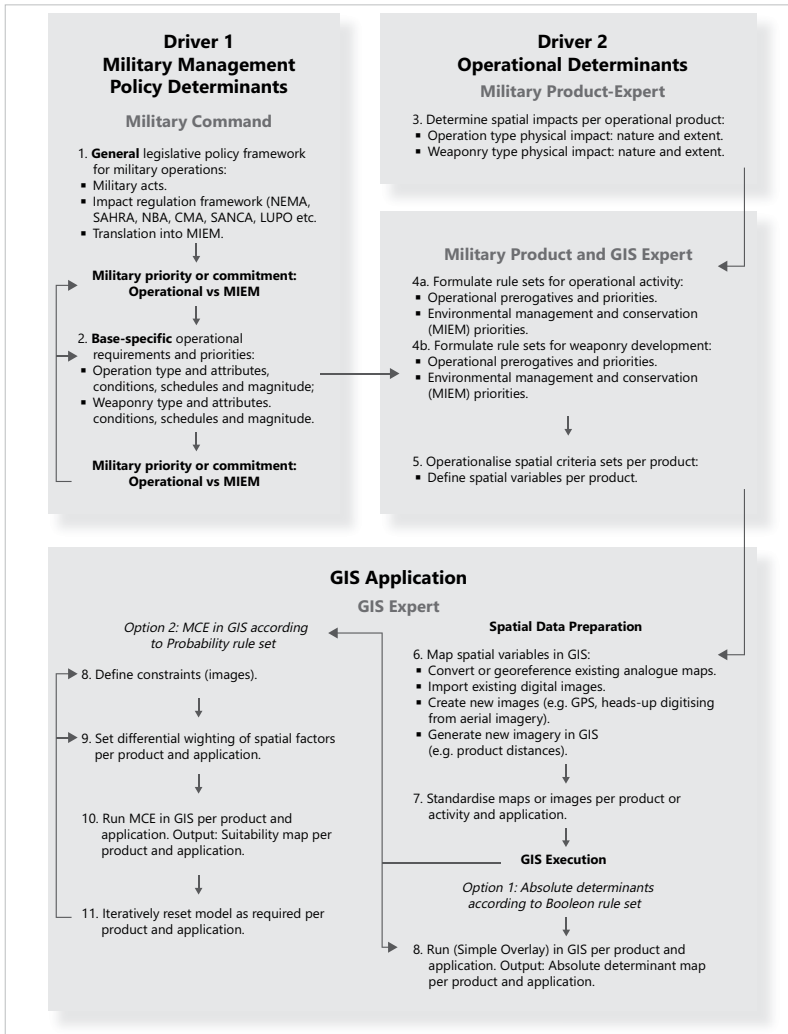


FIGURE 4.1 Flowchart of decision-making tasks and analytical options for supporting MIEM with GIS

Source: Marx op.cit, p. 127

In the operational decision-making mode the contributing data layers used to generate 'hard' choices are generated with a Boolean (1 = allowed/suitable, 0 = not allowed/unsuitable) value scale that allows an activity in a spatial cell or disallows it according to the variable of the layer. Since the 'sifting' of spatial cells occurs through an image overlaying procedure, it means that multiple layers can be overlaid to cumulatively generate a Boolean results layer, on which all cells that have the value 1 allow the activity and all zeroes disallow it. The point is that if one contributing layer has a zero in a

particular cell, that cell gets the value zero (disallowed) disregarding the possibility that all other criterion layers may have had 1s in that particular cell. Hence the designation as 'hard' decision-making. Some of the applications discussed later apply this mode.

The second decision-making mode follows a much different path. The contributing data layers used to generate its more subtle (arguably more realistic) decisions have ordinal values in their image cells, based on prior classification procedures to produce a suitability or sensitivity rating implied by the original raw values implication for the particular activity being influenced by or impacted on. These contributing criteria are also not simply overlain cumulatively, but the criteria are differentially weighted and then mathematically combined (see Van der Merwe et al.)<sup>59</sup> to generate a graded value range denoting a cell's suitability or sensitivity for the activity.

A final process allows the incorporation of Boolean imagery as 'constraints' disallowing activities in particular areas according to absolute no-go rules. Clearly, human decision-making is better accommodated or even emulated and led by this latter method – one particularly suited to environmental management, philosophically residing somewhat uncomfortably beside 'hard' military decision-making.<sup>60</sup>

## **Operationalised Multiple-Criteria Evaluation in Military Geographical Information Systems**

To operationalise MCE application in GIS and thus to bring the conceptual model to bear in military context on a specific MTA, a number of operational steps had to be performed:

- Develop a set of bounding geographical (impact) rules for each military-training activity expected to take place on the MTA.
- Design, implement and populate a rule base (i.e. database of rules) that captures the geographical manifestation and activity impacts of the conduct rules for each training activity.
- Create an electronic georeferenced geographical database of all relevant spatial features (installations, activity zones), on the MTA in the relevant GIS format (standardised sensitivity maps).
- Collaboratively design a weighted significance rating hierarchy for all activities and impact vulnerabilities.
- Develop and implement a protocol (inference engine) to model the potential environmental impacts of individual and combined military activities in the MTA space to demonstrate the capabilities of the system for an example training scenario.



## Environmental Impact of Military Operations

The first order of business in MCE application is to determine the range and nature of all possible impacting activities that take place on military terrain and to rate the importance of each as shown in table 4.1. As previously indicated, a MTA offers a uniquely diverse military activity space. Twelve types of weapons or ammunitions discharge, three types of parachuting, three types of diving, three types of surface swimming, three types of boat work, four types of vehicle training and seven types of miscellaneous training activities (ranging from hiking, climbing, flying to firing of arms) have been distinguished as major activity groups. For each of these 40 types, the affected locational or structural designations, high-impact season or affecting weather conditions and impacts range have been declared. Finally, a Likert-scale rating value between 1 (very low impact severity) and 5 (very high severity) was awarded. This value was deemed proportional to the extent, magnitude and severity of real or potential damage that has been observed or could reasonably (based on cumulative experience of a team of military officers consulted as part of the exercise) be expected to result from the performance of the particular activity type.

**TABLE 4.1** Summary extract from military activities, impacts and impact ratings on the MTA

MILITARY ACTIVITY	AFFECTED AND DESIGNATED LOCATIONS OR STRUCTURES	TEMPORAL CONDITIONS	WEATHER CONDITIONS	IMPACT DISTANCE THRESHOLD (M)	SEVERITY RATING
<b>WEAPONS/AMMUNITION (12 TYPES LISTED)</b>					
Pyrotechnics	All allocated shooting ranges and general training areas	All year	Not to be used during the dry season when the wind is stronger than 30 km/h.	500 m from all infrastructures	5
<b>PARACHUTING (3 VARIATIONS LISTED)</b>					
Land jumps: Static line/square/free-fall/tandem	Old cultivated fields	All year	No jumping if wind stronger than 24 km/h	300 m radius from drop zone (DZ) for any power lines and obstacles (obstacle 1 000 feet above elevation of DZ, 5 km away; 300-1 000 feet above elevation of DZ, 3 km away)	3
<b>DIVING (3 VARIATIONS LISTED)</b>					
Attack-diving	Pre-secured areas	All year	Up to sea state 4	Not nearer than 1 000 m to any vessel underway. No diving under vessels	5

TABLE 4.1 Summary extract from military activities, impacts and impact ratings on the MTA (continued)

MILITARY ACTIVITY	AFFECTED AND DESIGNATED LOCATIONS OR STRUCTURES	TEMPORAL CONDITIONS	WEATHER CONDITIONS	IMPACT DISTANCE THRESHOLD (M)	SEVERITY RATING
SURFACE SWIMMING (3 VARIATIONS LISTED)					
Beach landings	Particular Bays February-November	All year	No training above sea state 3		5
BOAT WORK (3 VARIATIONS LISTED)					
Surf work	Particular Bays areas	All year	No training above sea state 3		5
VEHICLE TRAINING (4 VARIATIONS LISTED)					
Sedan/trucks	MTA gravel roads	All year	No vehicles on gravel roads in case of excessive rains (more than 20 mm)	No vehicles on beaches except when recovering capsised boats or during medical emergencies	Sedan 1, trucks 3
MISCELLANEOUS TRAINING (7 VARIATIONS LISTED)					
Helicopter (fast roping/rapelling)	Particular ranges	All year	Wind not more than 30 km/h	Not closer than 50 m from any infrastructure such as power lines, etc.	5

Source: Adapted from Marx op. cit., pp. 132-135

## Geographical Database Development

For this project, a range of spatial data was collected for DMTA. This includes topographical, environmental, cultural, infrastructure and military data. All allocated areas for specific activities executed by operators, support personnel or visiting courses were mapped in accordance with the applicable variables. Activities were categorised in terms of location information, temporal factors, weather conditions and distance threshold as shown in table 4.1. A viability figure from 0-5 was allocated to each activity, taking the previously mentioned variables into consideration. The locational restrictions and environmental impacts of the different operational activities at the MTA were translated to a set of rules that can be used to model and map the potential environmental impact of each activity. The GIS data that was collected for the MTA were converted to a rasterised land unit database consisting of a square cell (10 x 10 metre) grid. The database stores, for each cell, values or codes for a number of attributes that quantify its distance from relevant geographical features and membership in relation to specific feature classes with activity relevance within the training area (e.g. denoting infrastructure like firing ranges, roads, power lines and areas considered to be environmentally sensitive).

With the land unit database completed, a separate (nonspatial) database was developed and populated with impact rules pertaining to each military activity type. Each rule in this rule base was linked to a specific military activity. For instance, no rock landings are allowed within 10 metres of the unique botterboom (*Tylecodon paniculatus*) stands on the northern shore of the MTA. By querying the system, a map can be created of areas where rock landings are permitted or where the environmental impact is minimised. MCE was used to develop a sensitivity map to be used in combination with the activities rule base to consider the environmental impact of individual or multiple activities.

A map server (web server capable of creating and serving maps via the internet) was configured at Stellenbosch University's Centre for Geographical Analysis (CGA) to accommodate, develop and demonstrate the system. A graphical user interface was developed to allow users to interact with the system via the internet.<sup>61</sup> The 5 metres Stellenbosch University Digital Elevation Model (SUDEM), currently the highest resolution and most accurate Digital Elevation Model (DEM) covering the entire South Africa,<sup>62</sup> was used. An abbreviated list of military activities, impacts and impact ratings on the MTA are shown in table 4.1. Much of the data in mapped format were collected using the Global Navigation Satellite system (GNSS or GPS) technology to ensure accuracy. Some data were also captured from high-resolution (0,75 metres) aerial imagery or obtained from

secondary sources (e.g. vegetation and geology maps). All of the data were stored in a digital GIS database using a common coordinate system (Lo19) and reference datum (WGS84), allowing exact-fitting superposed overlaying.

The spatial database contains overlays capturing the exact location of the features listed in table 4.2. Some of these features are in map format and hence became incorporated in the rules sets as the receiving phenomena upon which military activity might have some impact or, conversely, that might determine the possibilities and suitability for allowing particular types of military activity. From these base maps, using GIS utilities, further information overlays could be generated. Salient examples are distance buffering from chosen target and vulnerable features. GIS tools were also employed to capture further overlays that were operationally required to bring objectively calculated sensitivity to military activity of features into the modelling domain. This sensitivity mapping endeavour is discussed next.

TABLE 4.2 Spatial feature database compiled for the MTA

HUMAN ENVIRONMENT	TERRAIN	FLORA
<ul style="list-style-type: none"> <li>■ Heritage sites</li> <li>■ Paleontological resources</li> <li>■ Infrastructure</li> <li>■ Military facilities and activity areas</li> </ul>	<ul style="list-style-type: none"> <li>■ Digital Elevation Model</li> <li>■ Slope</li> <li>■ Aspect</li> <li>■ Geology</li> <li>■ FAUNA</li> <li>■ Terrestrial life forms</li> <li>■ Marine life forms</li> <li>■ Bats</li> </ul>	<ul style="list-style-type: none"> <li>■ Terrestrial natural vegetation</li> <li>■ Disused cultivated areas</li> <li>■ Marsh communities</li> <li>■ Flora on Meeuw Island</li> <li>■ Alien plant species</li> <li>■ Marine flora</li> </ul>

## Environmental Sensitivity Mapping

An environmental sensitivity map for the MTA was developed according to the principles of MCE explained earlier. From the military policies studied (step 3 in figure 4.1), it was clear that the main factors influencing the environmental sensitivity of a MTA are vegetation, current land use, the coast line and topography (in particular slope gradient and elevation). These factors were consequently selected. The colour scheme employed in maps was deliberately chosen to denote a range of ecological sensitivity to military and other activities. It ranges from highly sensitive (dark red) through the spectrum to dark green implying low sensitivity.

### *Vegetation sensitivity*

The MTA is home to a range of sensitive terrestrial flora. For the purposes of this study, an original vegetation-type map was developed<sup>63</sup> and spatially refined through accurate field survey and GPS demarcation of discernible stands. The field map was then digitised and each of the 11 vegetation types was rated from 1-5 (with 1 representing low and 5 high) according to its perceived sensitivity to military activity. West Coast thicket is generally considered botanically unique and hence sensitive to all forms of damage or removal. Some plant families are more highly rated based on the nature of the plant (size, consistency of stand), the stand size and its known sensitivity to specific types of human or natural interference. The granite and limestone soil and marsh communities, although small in comparison, were rated as having the highest sensitivity. The coastal shelf and dune sand communities are considered less sensitive, because they cover larger areas, have adapted to animal (and human) movement impacts and can therefore recuperate more readily from incidental damage or challenging climatic events. Note that the coastline is buffered for 500 metres from the shoreline for locational sensitivity, thereby creating an overlap with the vegetation criterion. Disused cultivated fields devoid of pristine natural vegetation are the least sensitive vegetation type. The spatial manifestation of the vegetation sensitivity rating is shown in figure 4.2a. It shows that most of the MTA is covered by vegetation with moderate to high sensitivity.

### *Land use sensitivity*

Current land use types in the MTA were mapped using a combination of field visits and visual interpretation of aerial photographs. The sensitivity of the eight land uses was rated using the standardised 1-5 rating scale. Beaches, dunes and marshland were deemed highly sensitive, while natural vegetation as a group was considered moderately sensitive to operations. Disturbed areas (i.e. old cultivated fields and shooting ranges) were considered the least sensitive land uses. In addition, structures, roads and cultural artefacts were regarded as no-go areas (no damage allowed) and were consequently also rated as highly sensitive to operations. Due to the extreme sensitivity of heritage sites, a 200 metres buffer area was reserved around all cultural artefacts.

The resulting land use sensitivity map is shown in figure 4.2b. Its spatial patterns highlight the 'islands' of sensitivity around the 'occupied' built-up enclaves and along beaches. Core land areas on both the peninsula and the main land area are relatively insensitive to military activity on this criterion.

### *Coastline sensitivity*

The relatively long MTA coastline is ideal for operations training. However, some parts of the coastline are highly sensitive and should be protected from possible damage caused by training activities. A field survey of the coast was conducted with the resulting feature classification map shown in figure 4.2c. The fairly long (23,7 kilometres) and decidedly diverse coastline ranges from flat sandy beaches in the centre to vertical cliffs in the north. Nine coastal characteristics that are important from both ecological and concomitant military operational perspectives were distinguished, based on morphology of surface material (sandy, pebbly, rocky) and topography (dunes, cliffs). Clearly, the fringed sandy fore dunes and the sandy high vegetation are the most sensitive parts of the coastline. The cliffed coast was deemed the least sensitive, due to its difficult and inaccessible terrain and therefore the low likelihood of movement activity there.

Spatially applied, the coastline map was converted to a sensitivity map with sensitivity ratings applied to a 250 metres wide buffer strip along the coastline as shown in figure 4.2c – thereby imposing the coastline influence (actually a zone and not a mere line) more realistically. The sandy beaches (6,5 kilometres) are popular breeding grounds for endangered species of bird such as the black oystercatcher and hence highly sensitive to all military activities. The Riet Bay (in centre) shore carries an almost similarly high sensitivity rating due to the marine vegetation and fauna found in its shallow waters. From an operational perspective ease of vehicle and personnel movement (e.g. along and onto the 14,7 kilometres platformed coastline), as well as the potentially detrimental impact of exploding munitions on fauna and flora are taken into account when denoting sensitivity.

### *Topographic vulnerability*

Two topographical factors, namely slope gradient and elevation, were considered in the MCE. Slope gradient was selected because erosion potential increases as slope gradient increases. Slope gradient was calculated as a percentage using a digital elevation model and reclassified into five significant classes of steepness. Each class was then assigned a sensitivity rating based on the erosivity of slope classes. The sensitivity ratings were applied to the land unit database to produce figure 4.2d, a sensitivity map of slope gradient. Much of the MTA has a relatively low sensitivity in terms of slope gradient, with only a few small coastal fringe areas in the south and north-west having a high sensitivity.

Additionally, height above sea level (elevation) was calibrated for high (value 5), moderate (3) and low-lying (1) terrain, along 40 metres height intervals. Absolute height was deemed important from a sensitivity vantage because the highest ranges in the landscape are visually most exposed, surface features are hard and generate runoff and often richer, more unique and sensitive species (faunal and floral) congregate there. A map of elevation sensitivity is shown in figure 4.2e.

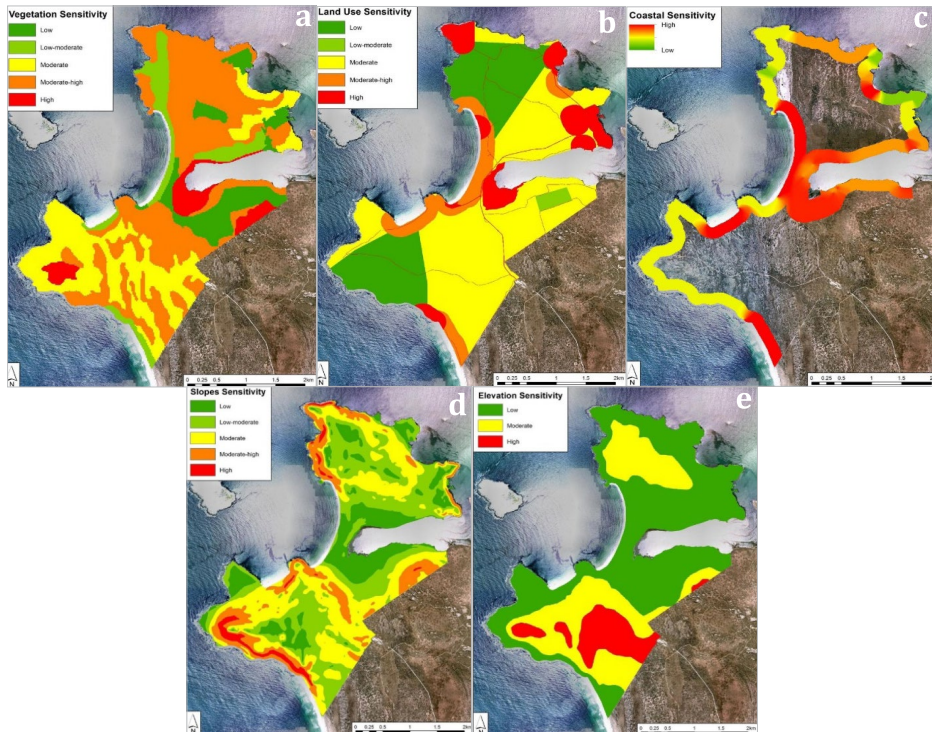


FIGURE 4.2 (a-e)Environmental sensitivity rating: (a) vegetation, (b) land use types, (c) coastline, (d) slopes and (e) elevation



## Operational Rule Set Development

TABLE 4.3 Pyrotechnics rule set in logical structure

RULE	1	2	3	4	5
INCLUDE/ EXCLUDE	Include	Exclude	Exclude	Exclude	Exclude
JANUARY	1	1	1	1	1
FEBRUARY	1	1	0	0	1
MARCH	1	1	0	0	1
APRIL	1	1	0	0	1
MAY	1	1	0	0	1
JUNE	1	1	0	0	1
JULY	1	1	0	0	1
AUGUST	1	1	0	0	1
SEPTEMBER	1	1	0	0	1
OCTOBER	1	1	0	0	1
NOVEMBER	1	1	0	0	1
DECEMBER	1	1	1	1	1
WIND (KPH)	< 30	< 30	< 30	< 30	< 30
RAIN (MM)	> = 0	> = 0	> = 0	> = 0	> = 0
SEA STATE	> = 0	> = 0	> = 0	> = 0	> = 0
DISTANCE	> = 0	< = 500	> = 0	> = 0	< = 1 000
LOCATION	All areas within boundary	Islands	Beaches	Riet Bay	Staff quarters

Rules regulating the conduct of each activity type to minimise its impact on the operational environment were formulated for each of 35 activities as extracted in the example in table 4.3 in a semi-structured linguistic format, which incorporates several constraint variables for each activity. In addition to described spatial features and distance thresholds from features, constraints were also specified for temporal conditions and weather

conditions. To create the required spatial management system, the linguistic rule set was converted into a logical structure incorporating all of the constraint variables. To demonstrate this, table 4.3 shows the original semi-structured linguistic set of rules for pyrotechnics. To get from the linguistic rule set to the logical set was not straightforward. Several collaborative work sessions involving the technical GIS team were required. Five activity rule sets captured the rules for this activity type. Each set specifies whether some areas are excluded or all are included, whether there are temporal constraints allowing (month = 1) or disallowing (month = 0) the activity and under what wind, rain, sea state or distance at particular locations these would prevail. It should be noted, that rule application requires a Boolean GIS operation in which an activity is allowed or not. The spatial outcomes of the application of rule 5 are shown in figure 4.3, although all the rules were originally implemented. It shows the area available (area in grey) for pyrotechnics exercises after the rule application (pyrotechnics not being allowed in the central area). Activity rules can routinely be added, deleted or modified as new environmental or military technology knowledge becomes available, environmental regulation is altered or military operational imperatives are reformulated without affecting the operational integrity or practical implementation of the system.

From the foregoing it should be clear that the rules that are applied on the land unit database depend on the activity, date (month of the year), as well as wind, rain and sea state. These conditions are provided by the operator on the day of action, applied in the system and the result mapped to guide activity. Contingency planning at the time of operational or strategic scheduling of actions allows all rules to be implemented as possible scenarios. The next section explains how environmental sensitivity of features can be incorporated in the system through the use of multi-criteria spatial analysis.

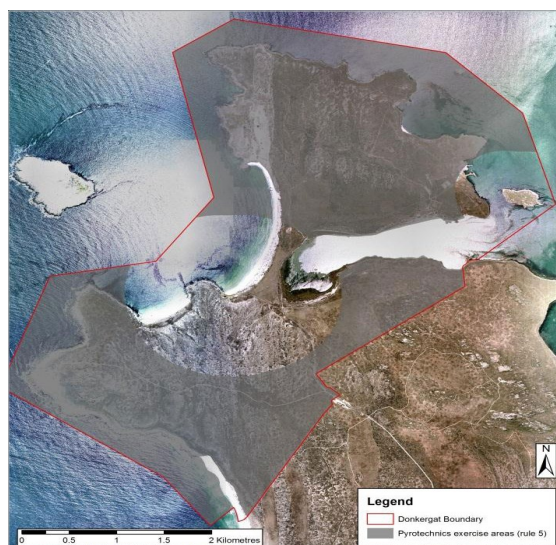


FIGURE 4.3 Spatial application of pyrotechnics rule 5

## Multiple-Criteria Evaluation: Criteria Weighting and Weighted Overlay

The selected criteria were subjected to the Analytical Hierarchy Process (AHP)<sup>64</sup> to determine their relative importance (contribution) to environmental sensitivity in the MTA. The pair-wise comparison of the criteria resulted in relative weights calculated for each variable layer in table 4.4. It shows vegetation is deemed the most important determinant of environmental sensitivity and height (elevation) is considered to have the least impact on environmental sensitivity, since military activity is not confined by it in isolation, but actually in combination with the natural features (like vegetation species) located there. The AHP calculation software available at <http://www.iscsenshu-u.ac.jp/~thc0456/EAHP/AHPweb.html> was used to calculate the consistency index (0,02) of the matrix and to determine the relative weight (importance) of each variable. As seen in table 4.4, vegetation contributes 42% of the 'influence', i.e. plays the strongest role in determining environmental sensitivity. This is followed by land use (26%), coastal features (16%), slope gradient (10%) and height (6%). Of course, one has to recognise that the objective of the application (whether driven by the operational or by the ecological imperative) determines the weights awarded under the specific circumstance. This aspect is most readily subjected to iterative experimentation to ensure best results of the MCE application.

TABLE 4.4 Pair-wise comparison matrix

VARIABLE	VEGETATION	LAND USE	COASTAL TOPO	SLOPE	HEIGHT	WEIGHT
Vegetation	1					0,42
Land use	2	1				0,26
Coastal topo	3	2	1			0,16
Slope	4	3	2	1		0,10
Height	5	4	3	2	1	0,06

The individual criterion maps were functioned using these weights. ArcMap's Raster Calculator was used to create a composite environmental sensitivity map as depicted in figure 4.4.

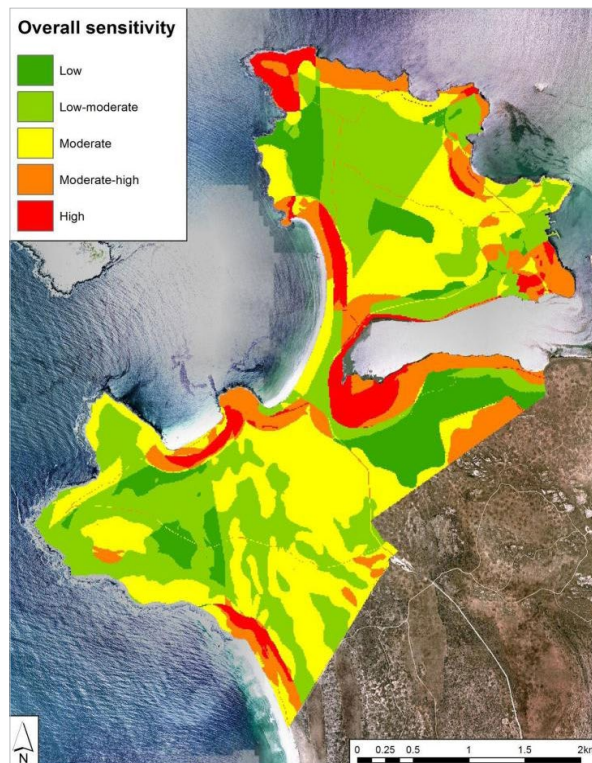


FIGURE 4.4 Composite environmental sensitivity

This map demonstrates the outcome of the cumulative decision-making described in the preceding sections. Areas of specific sensitivity designation can be clearly relayed to the ratings of particular constituent factors or criteria portrayed earlier. Considering the cumulative influence of the constituent layers and – most importantly – their relative weighting, it is clear that the areas bordering much of the sandy coastline, as well as along occupied, history-rich areas and where coastal dunes occur, are highly sensitive. The old fields and adjoining natural areas are generally fit to be considered as ‘sacrificed’ areas for operational purposes. Note that this product represents the outcome of the final step 10 in the MCE process of figure 4.1. A reminder: decision makers (military officers and planners in this case) are now empowered to reconsider and revisit various earlier steps as required until an acceptable, functional, operational plan – still in compliance with MIEM principles – is finalised. The next section explains how the environmental sensitivity map can be incorporated into the SDSS to minimise the environmental impact of training activities.

## **Towards a Spatial Decision Support System**

Following the capture of all spatial data and having completed the MCE analysis, the development of the operational web-based system could commence. The web-based system consists of three main components: The web application, developed in Adobe Flex, which provides the interface for the user to view and manage the data; the ArcGIS Server Map Service, which feeds the spatial layers to the web application, along with their pre-configured symbology; the ArcSDE Geodatabase, which stores the spatial layers accessed by the map service. These systems are not fully explored here because of space and security restrictions.

The web application includes activation of several information layers. A topographical base map layer provides context and orientates the user. The user may also choose to display a sensitivity raster or a high-resolution aerial photograph as backdrop. In both cases, layers detailing the boundaries and roads are provided. Depending on the operation selected and the conditions specified, the web application loads a semi-transparent layer that greys out the areas where a particular training activity is not allowed (as in figure 4.3).

When affected areas for a range of military activities, such as shooting, urban training, diving, survival, mountaineering and rock landings are plotted together with the other SDSS criteria, the cumulative outcome displayed in figure 4.5 shows that only a very small portion of the peninsula is available for all training simultaneously.

By combining different layers representing activities and by incorporating the environmental sensitivity within the areas where the activities are allowed, the user can geographically plan operations that limit environmental damage. A more extensive demonstration of the system for operational planning<sup>65</sup> shows that it is quite user-friendly and intuitive. More complex scenarios with various combinations of exercises can also be produced using the available tools. The incorporation of the environmental sensitivity layer as background allows the user to select sites and routes that will limit environmental impact. The graphic user interface allows various options for producing high-quality maps, which can be used during planning, as guidance in the field or in post-operational reports. The system usage can also be extended to include alternative activity scenarios, employ different GIS functions and database layers (including ones experimenting with differential environmental sensitivity).

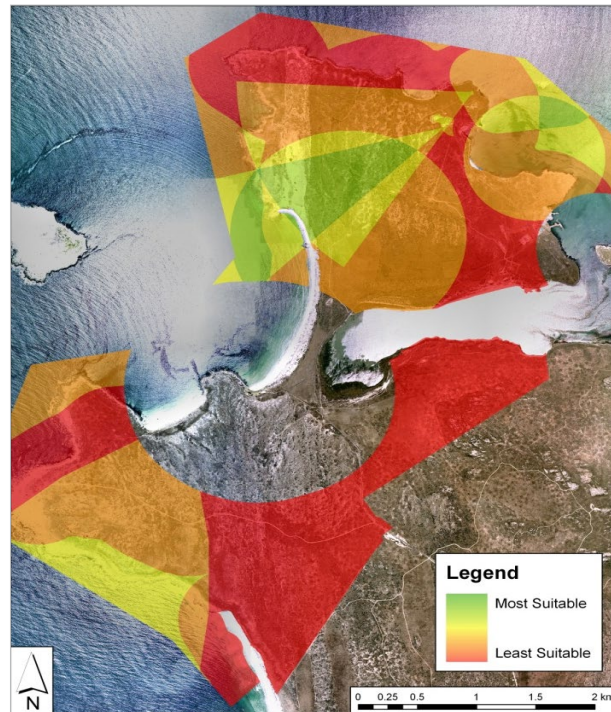


FIGURE 4.5 Composite suitability for all training activities

## Conclusion and Future Development

This research managed to establish a comprehensive record and image of the impact range that diverse military activities have on the complex environment that most military terrains occupy. Especially the spatial variation in impact intensity and potential cumulative impact on both physical, human and social elements of the environment were highlighted. The building of an appropriate spatial database to support a spatial decision support system on a GIS platform was elaborated and the innovative application of such an SDSS on a MTA was designed and demonstrated. It is believed the efficacy of such a system in meeting the demands for military integrated environmental management goals in South Africa became evident.

The operational application of the SDSS has potential for exploitation further afield in the military. The system can be adapted for more universal application (i.e. for other areas, as well as for other activities). Technologically, an interface for hand-held devices (e.g. GPS, smartphones, etc.) can, for instance, be developed to provide geographical information from the field in an augmented reality format. The system's functionality can be extended from a planning tool to a planning and operational tool by improving it to the level where it can accept data from mobile personal data assistant (PDA) devices of operators in the field and update the central database in real-time. Further aspects of reality that have to be factored into system development and application include catering for the eccentricities of nature, regular and extreme realities of military conduct and the possibilities inherent to ever more refined technological gadgetry.



## ENDNOTES AND REFERENCES

1. Marx, J.T. 2015. Military integrated environmental management at the Donkergat military-training area. Dissertation presented for degree PhD. Stellenbosch University.
2. Macleod, I. 1998. Use of COTS technology in C2 information systems: Balancing the benefits and risks. *Journal of Battlefield Technology*, 1:23-28.
3. Rehak, L. 2010. *Mobile geospatial information systems for land force operations: Analysis of operational needs and research opportunities*. Toronto: Defence Research and Development Canada.
4. Singer, S.; Wang, G.; Howard, H. & Anderson, A. 2012. Environmental condition assessment of USA military installations using GIS based spatial multi-criteria decision analysis. *Environmental Management*, 50:329-340. <https://doi.org/10.1007/s00267-012-9873-y>
5. Loechel, A.J.; Mihelcic, G. & Pickl, S. 2012. An open source approach for a military situational awareness system. *Proceedings of the 45<sup>th</sup> Hawaii International Conference on System Sciences*. New York: Institute of Electrical and Electronics Engineers (IEEE). pp. 1462-1471. <https://doi.org/10.1109/HICSS.2012.109>
6. Henrico, S.J. 2017. *Analysing the practical feasibility of using free and open source software for geographical information systems (FOSSGIS) in military operations*. Thesis presented for degree Master of Arts. University of Pretoria.;  
Marx, 2015, op. cit.
7. Chen, C-C.; Hwang, D.; Wang, S. & Schonfeld, P. 2011. *Incorporating GIS-based visibility analysis into a military transportation path planning algorithm*. Paper presented at the Transportation Research Board 90<sup>th</sup> Annual Meeting, Washington DC.;  
Ding, J.' Wu, K.H. & Ding, Z.B. 2010. Study on the military environmental information management with GIS. *Advanced Materials Research*, 113:561-564. <https://doi.org/10.4028/www.scientific.net/AMR.113-116.561>  
Jha, M.K.; Karri, G.A. & Kang, M-W. 2010. A military path planning algorithm using visualization and dynamic GIS. *Proceedings of the 4<sup>th</sup> WSEAS international conference on Computer engineering and applications*. Cambridge, Stevens Point, Wisconsin, USA. Cambridge: World Scientific and Engineering Academy and Society (WSEAS).;  
Jun, W.; Chao, X.; Fan, J. & Yue, Z. 2011. Research of military logistics management information system based on the integrated technology of workflow and GIS. *Proceedings of the 2<sup>nd</sup> International Conference on Digital Manufacturing & Automation (ICDMA)*. Hunan: IEEE Computer Society.;  
Kang, M-W.; Jha, M.K. & Karri, G. 2010. Determination of robot drop location for military path planning using GIS application. *Proceedings of the 4<sup>th</sup> WSEAS international conference on Computer engineering and applications*. Stevens Point, Wisconsin, USA. Cambridge: World Scientific and Engineering Academy and Society (WSEAS).;  
Li, N.; He, M.; Ren, Z. & Gong, G. 2014. CGF-SDP: Development of simulation scenario and scenario editor. *Applied Mechanics and Materials*, 441:431-434.;  
Luo, C.; Cai, L.; Huang, M.; Lu, Y.; Liu, L. & Li, P. 2011. Assessment of military airfield obstacle-free space-based on GIS. *Transactions of Nanjing University of Aeronautics & Astronautics*, 28:294-299. <https://doi.org/10.4028/www.scientific.net/AMM.441.431>



8. Mendoza, G.A.; Anderson, A.B. & Gertner, G.Z. 2002a Integrating multi-criteria analysis and GIS for land condition assessment: Part 1 – Evaluation and restoration of military-training areas. *Journal of Geographic Information and Decision Analysis*, 6:1-16.;  
Mendoza, G.A.; Anderson, A.B. & Gertner, G.Z. 2002b Integrating multi-criteria analysis and GIS for land condition assessment: Part 2 – Allocation of military-training areas. *Journal of Geographic Information and Decision Analysis*, 6:17-30.
9. Tuvesson, O. 2001. *Integrating GIS and multicriteria analysis in the search for roadside bombs*. Thesis presented for degree BSc. University of Gävle, Sweden.
10. Sánchez-Lozano, J.M. & Bernal-Conesa, J.A. 2017. Environmental management of Natura 2000 network areas through the combination of Geographic Information Systems (GIS) with Multi-Criteria Decision Making (MCDM) methods. Case study in south-eastern Spain. *Land Use Policy*, 63:86-97. <https://doi.org/10.1016/j.landusepol.2017.01.021>  
Singer, S.; Wang, G.; Howard, H. & Anderson, A. 2012. Environmental condition assessment of USA military installations using GIS based spatial multi-criteria decision analysis. *Environmental Management*, 50:329-340.
11. Bell, J. & Griffis, S. 2015. Military Applications of Location Analysis. In: H. Eiselt & V. Marianov (eds.), *Applications of Location Analysis. International Series in Operations Research & Management Science*, Springer. pp. 403-433. [https://doi.org/10.1007/978-3-319-20282-2\\_17](https://doi.org/10.1007/978-3-319-20282-2_17)  
Brynielsson, J.; Lindquist, S. & Luotsinen, L. 2016. Efficient implementation of simulation support for tactical-level military training. *Proceedings. The 2016 Interservice/Industry Training, Simulation, and Education Conference (IIITSEC 2016)*. Arlington, Virginia: National Training and Simulation Association (NTSA). pp. 1-12.;  
Li, 2014, et al., op. cit.
12. Baylon, A.M. & Santos, E.M.R. 2013. Introducing GIS to TransNav and its extensive maritime application: An innovative tool for intelligent decision making? *International Journal on Marine Navigation and Safety of Sea Transportation*, 7(4):557-566. <https://doi.org/10.12716/1001.07.04.11>
13. Ayers, P.D.; Anderson, A.B. & Wu, C. 2005. Analysis of vehicle use patterns during field training exercises to identify potential roads. *Journal of Terramechanics*, 42:321-338. <https://doi.org/10.1016/j.jterra.2004.10.008>
14. Cameron, F. 2005. Remote sensing, geographic information systems, and operational research in urban operations. *Canadian Army Journal*, 8:31-38.;  
Liao, S-H.; Sun, B-L. & Wang, R-Y. 2003. A knowledge-based architecture for planning military intelligence, surveillance, and reconnaissance. *Space Policy*, 19:191-202. [https://doi.org/10.1016/S0265-9646\(03\)00020-1](https://doi.org/10.1016/S0265-9646(03)00020-1)  
Tuvesson, 2001, op. cit.
15. Chen, et al., 2012, op. cit.;  
Jha, M.K.; Karri, G.A. & Kang, M-W. 2010. A military path planning algorithm using visualization and dynamic GIS. *Proceedings of the 4<sup>th</sup> WSEAS international conference on Computer engineering and applications*. Cambridge, Stevens Point, Wisconsin, USA. Cambridge: World Scientific and Engineering Academy and Society (WSEAS).;  
Kang et al., 2010, op. cit.;  
Luo et al., 2011, op. cit.;

- Rehak, 2010, op. cit.;
- Zhao, T.; Huang, J.; Cheng, G.; Chen, C. & Shi, J. 2016. *Maneuvering route safety planning for military vehicles during wartime*. MATEC Web of Conferences, 81:1-6.
16. Jafari, P. & Sadeghi-Niaraki, A. 2013. Use of ubiquitous technologies in military logistic system in Iran. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 40:215-220. <https://doi.org/10.5194/isprsarchives-XL-1-W3-215-2013>
  17. McDonald, E.V.; Bacon, S.N.; Bassett, S.D.; Amit, R.; Enzel, Y.; Minor, T.B.; McGwire, K.; Crouvi, O. & Nahmias, Y. 2016. Integrated Terrain Forecasting for Military Operations in Deserts: Geologic Basis for Rapid Predictive Mapping of Soils and Terrain Features. In: E. McDonald & T. Bullard (eds.), *Military Geosciences and Desert Warfare. Advances in Military Geosciences*. New York: Springer. pp. 353-375.
  18. Kleiner, M.; Carey, S.; Roberts, J.; Altenau, M.; Yu, H.; Gates, B.Q. & Nielsen, E. 2007. Geospatial battle management language. *Proceedings of the 2007 Summer Computer Simulation Conference*. San Diego: Society for Modelling & Simulation International.;
- Loechel et al., 2012, op. cit.
19. Kettani, D. & Mamar, Z. 1997. *Towards a qualitative spatial model for military GIS. Proceedings of the IEEE International Conference on Robotics and Automation*. New York: Institute of Electrical and Electronics Engineers (IEEE).;
- Macleod, 1998, op. cit.;
- Wei, X.; Feng, J.; Feng, S. & Zhai, Y. 2013. Design of military logistics management system based on internet of things technology. In: E. Qi, J. Shen, & R. Dou (eds.), *The 19<sup>th</sup> International Conference on Industrial Engineering and Engineering Management*. Berlin: Springer.
- [https://doi.org/10.1007/978-3-642-38391-5\\_156](https://doi.org/10.1007/978-3-642-38391-5_156)
20. Godschalk, S.K.B. 1998. Green soldiering – integrated environmental management as a major contribution towards military mission achievement. *Proceedings of the 14<sup>th</sup> International Logistics Congress*. Sun City, South Africa, 24-27 November.
  21. Andersen, M.C.; Thompson, B. & Boykin, K. 2004. Spatial risk assessment across large landscapes with varied land use: Lessons from a conservation assessment of military lands. *Risk Analysis*, 24:1231-1242. <https://doi.org/10.1111/j.0272-4332.2004.00521.x>
- Doxford, D. & Hill, T. 1998. Land use for military-training in the UK: The current situation, likely developments and possible alternatives. *Journal of Environmental Planning and Management*, 41:279-297. <https://doi.org/10.1080/09640569811597>
22. Ferro, M.A.C. & Santos, M.O.R.M. 2012. Environmental management system (EMS) for military activities – strategies and policies of American, Canadian, Brazilian and NATO Armies. *Coleção Meira Mattos, Revista das Ciências Militares*. p. 27. s.p.  
[Online]: <http://ssrn.com/abstract=2172535> [Accessed 27 January 2015].
  23. DeFraités, R.F. 2007. Gaining experience with military medical situational awareness and geographic information systems in a simulated influenza epidemic. *Military Medicine*, 72:1071-1076. <https://doi.org/10.7205/MILMED.72.10.1071>
  24. Doxford & Hill, 1998, op. cit.;
- Ferro & Santos, 2012, op. cit.

25. Gaffer, R.L.; Flanagan, D.C.; Denight, M.L. & Engel, B.A. 2008. Geographical information system erosion assessment at a military-training site. *Journal of Soil and Water Conservation*, 63:1-10.  
<https://doi.org/10.2489/jswc.63.1.1>
26. Ayers, D. 2016. Using GIS to Assist in Social Impact Assessments at Military Installations. *Pursuit – The Journal of Undergraduate Research at the University of Tennessee*, 7(1):1-8.
27. Mendoza et.al., 2002a, op. cit.;  
Mendoza et al., 2002b, op. cit.;  
Singer et al., 2012, op. cit.
28. Andersen et al., 2004, op. cit.;  
Cameron, 2005, op. cit.
29. Chen et al., 2012, op. cit.
30. Ding et al., 2010, op. cit.;  
Kettani & Maamar, 1997, op. cit.;  
Liao et al., 2003, op. cit.
31. Kleiner et al., 2007, op. cit.
32. Flores, A.N.; Entekhabi, D. & Bras, R.L. 2014. Application of a hillslope-scale soil moisture data assimilation system to military trafficability assessment. *Journal of Terramechanics*, 51:53-66.  
<https://doi.org/10.1016/j.jterra.2013.11.004>  
Lee, E.S.; Lee, H.K.; Kim, K.B. & Kim J.B. *A study on the creation of VITD based on Quantum GIS. Information*, 19(1):245-250.;  
Luo et al., 2011, op. cit.
33. Rehak, 2010, op. cit.
34. Andersen et al., 2004, op. cit.
35. Gaffer et al., 2008, op. cit.
36. Mendoza et al., 2002a, op. cit.;  
Mendoza et al., 2002b, op. cit.
37. Andersen et al., 2004, op. cit.;  
Ayers et al., 2016, op. cit.;  
Cameron, 2005, op. cit.;  
Chen et al., 2012, op. cit.;  
Jha et al., 2010, op. cit.;  
Kang et al., 2010, op. cit.;  
Luo et al., 2011, op. cit.;  
Tuveson, 2001, op. cit.
38. Maio, C.V.; Tenenbaum, D.E.; Brown, C. & Gontz, A.M. 2013. Application of geographic information technologies to historical landscape reconstruction and military terrain analysis of an American Revolution Battlefield: Preservation potential of historic lands in urbanized settings, Boston, Massachusetts, USA. *Journal of Cultural Heritage*, 14(4):317-331.  
<https://doi.org/10.1016/j.culher.2012.08.002>

- McNutt, R.K. 2014. *Finding forgotten fields: a theoretical and methodological framework for historic landscape reconstruction and predictive modelling of battlefield locations in Scotland*. Dissertation presented for degree PhD. University of Glasgow.
39. Nagy, E. 2017. *The limes of Roman Dacia near the auxiliary fort of Bologa. An application of GIS viewshed analysis*. Thesis presented for degree Master of Science. Lund University.
  40. He, J.; Liu, J.; Xu, S.; Wu, C. & Zhang, J. 2015. A GIS-based cultural heritage study framework on continuous scales: A case study on 19<sup>th</sup> century military industrial heritage. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 40:215-222. <https://doi.org/10.5194/isprsarchives-XL-5-W7-215-2015>
  41. Joos, G. 2012. GIS in defence. In: W. Kresse & D. Danko (eds.), *Springer Handbook of Geographic Information*. Berlin: Springer. pp. 477-501;  
Jun et al., 2011, op. cit.;  
Kettani & Maamar, 1997, op. cit.
  42. Cameron, 2005, op. cit.
  43. DeFraites, 2007, op. cit.
  44. Cheng, C.R.G. & Thompson, R.G. 2016. Application of boolean logic and GIS for determining suitable locations for temporary disaster waste management sites. *International Journal of Disaster Risk Reduction*, 20:78-92. <https://doi.org/10.1016/j.ijdr.2016.10.011>
  45. Chadwick, B.; Wang, P.F. & Brand, M. 2015. A Methodology for Assessing the Impact of Sea Level Rise on Representative Military Installations in the Southwestern United States. San Diego, CA: Space and Naval Warfare Systems Center Pacific.; Hsieh, B. & Ratcliff, J. 2015. Application of self-organizing feature maps to water resources projects. *Proceedings of the International Conference on Artificial Intelligence (ICAI), Athens*. 704-710.
  46. Doxford & Hill, 1998, op. cit.;  
Ferro & Santos, 2012, op. cit.
  47. Marx, 2015, op. cit.;  
Van der Merwe, J.H.; Marx, J.T.; Stephenson, G.; Pauw, T. & Van Niekerk, A. 2013. *TSO-GOEMS*. CGA Report, 01. Stellenbosch: Centre for Geographical Analysis, Stellenbosch University.
  48. Ascough, J.C.L.; Rector, H.D.; Hoag, D.L.; McMaster, G.S.; Van den berg, B.C.; Shaffer, M.J.; Weltz, M.A. & Ahjua, L.R. 2001. Multicriteria spatial decision support systems for agriculture: Overview, applications and future research directions. In: A.E. Rizzoli & A.J. Jakeman (eds.), *Integrated assessment and decision support. Proceedings of the 1<sup>st</sup> biennial meeting of the IEMSS*, Lugano: IEMSS. pp. 175-180.;  
Densham, P.J. 1991. Spatial decision support systems. In: D.J. Maguire, M.F. Goodchild, & D.W. Rhind (eds.), *Geographical information systems: Principles and applications*. Harlow: Longman. pp. 403-412.;  
Goodchild, M.F. & Densham, P.H. 1990. *Research initiative six, spatial decision support systems: Scientific report for the specialist meeting. Technical report No 90-95*. Santa Barbara: National Center for Geographic Information and Analysis.
  49. Ascough et al., 2001, op. cit.
  50. Van Niekerk, A. 2012. Developing a very high resolution DEM of South Africa. *Position IT*. November-December. pp. 55-60.

51. Henrico, 2017, op. cit.
52. Chang, K. 2006. *Introduction to geographic information systems*. 3<sup>rd</sup> ed. New York: McGraw Hill;  
Clarke, K.C. 2003. *Getting started with geographic information systems*. Upper Saddle River: Prentice Hall;  
De Mers, M.N. 2005. *Fundamentals of geographic information systems*. 3<sup>rd</sup> ed. New York: Wiley & Sons.
53. Longley, P.A.; Goodchild, M.F.; Maquire, D.J. & Rhind, D.W. 2002. *Geographic information systems and science*. Chichester: John Wiley & Sons. p. 278.
54. Henrico, 2017, op. cit.
55. Chang, 2006, op. cit.
56. Van der Merwe, J.H. 1997. GIS-aided land evaluation and decision-making for regulating urban expansion: A South African case study. *GeoJournal*, 43:135-151;  
Van der Merwe et al., 1997, op. cit.
57. Marx, 2015, op. cit.
58. Godschalk, 1998, op. cit.
59. Van der Merwe et al., 1997, op. cit.
60. Ibid.
61. Ibid.
62. Van Niekerk, 2013, op. cit.
63. Boucher C. & Jarman, M.L. 1977. The vegetation of the Langebaan area, South Africa. *Transactions of the Royal Society of South Africa*, 42:241-272. <https://doi.org/10.1080/00359197709519916>
64. Van der Merwe et al., 1997, op. cit.
65. Ibid.



# PART 3

The Southern African  
Maritime Domain

# Maritime Southern Africa



Mark Blaine 

The sea is a vital national interest and that is why we maintain the Navy ... We are a maritime nation trading all over the world. We accept our obligation to combine with other maritime nations to uphold the freedom of the seas and to protect our national interests through naval power.

*Nelson Mandela, Cape Town, 5 April 1997*

## Introduction

South Africa is a maritime nation with an island economy. The same could well be said for the South African Development Community (SADC) which has only in the recent past started to realise the importance of the ocean for the growth of its economies. With the negative maritime security developments off the East and West coasts of Africa such as piracy and armed robbery, the region realised that it would have to develop a common strategy to tackle these issues.



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To fully understand the role that the region could play in the safeguarding of its maritime lanes, this document will examine the maritime area, as well as maritime security challenges and actions of the region. Due to the dominant role that the South African Navy (SAN) plays in the region, the document will investigate its historic roots and possible reasons for its current dominance.

This chapter was researched using a qualitative approach to describe and interpret information. Primary sources of information were gathered in the form of relevant legislation and regulations governing maritime security on the national, regional and global levels and included legislation, policies, regulations and directives. Secondary sources of information were collected from books, journal articles, thesis dissertations and abstracts, reports, presentations, study guides and newspapers.

The aim of this chapter is thus to determine how the maritime security challenges faced by the SADC contributed to the current composition/state of the SAN.

## International Maritime Zones<sup>1</sup>

The demarcation and delimitation of the maritime zones throughout the world is internationally governed and enforced by the 1982 United Nations Convention of the Law of the Sea (UNCLOS). This convention came into force in 1994 and has been ratified by 159 countries around the world. The purpose of the convention is to establish a comprehensive set of rules that would govern the oceans.<sup>2</sup>

Pursuant to the convention: Every state has the right to establish the following:

- The breadth of its *territorial sea* up to a limit not exceeding 112 nautical miles.
- A *contiguous zone* up to 24 nautical miles from the shoreline for purposes of enforcement of customs, fiscal, immigration or sanitary laws.
- An *Exclusive Economic Zone (EEZ)*, adjacent to the contiguous zone and up to 200 nautical miles from the shoreline for purposes of exploration and exploitation, conserving and managing the natural resources (living or dead) of the waters superjacent to the seabed and of the seabed and its subsoil.
- A *continental shelf* that extends beyond the territorial sea through the natural prolongation of its land territory to the outer edge of the continental margin. The limits shall not extend beyond the limits provided by the convention and in all cases not beyond 350 nautical miles.

The ocean and seabed, as well as the subsoil beyond these limits of national jurisdiction are for the common heritage of mankind and are commonly referred to as the high seas. UNCLOS makes provision for an international seabed authority tasked with



organising, carrying out and controlling activities associated with the exploitation of the resources of the high seas.

### *Jurisdictional Zones*

- *Internal Waters.* Jurisdiction flows automatically from all sovereignty exercised over the land territory of the state.
- *Territorial Sea.* The state retains full sovereignty except for rights of innocent passage.
- *Contiguous Zone.* States may exercise the control necessary to punish or prevent infringements of its customs, fiscal, immigration or sanitary laws and regulations.
- *Exclusive Economic Zone and Continental Shelf.* The state has the right for the use of the living and non-living natural resources, to use the zone for economic purposes and the right to construct, authorise and regulate the construction of artificial islands and certain installations and structures. All states however have the right of innocent passage (freedom of navigation) and overflight and the right to lay submarine cables and pipelines.

### *Navigation*

- *Internal Waters.* The state has the exclusive right to define rights for navigation.
- *Territorial Sea.* Foreign ships have right of innocent passage as long as it is not prejudicial to peace, good order and security of the applicable state.
- *Exclusive Economic Zone and Continental Shelf.* All ships have freedom of navigation.

### *Oil, Gas and Mineral Resources*

- *Internal Waters and Territorial Sea.* The state has the exclusive right of exploitation.
- *Exclusive Economic Zone and Continental Shelf.* The state has the exclusive right of exploitation, except when it will conflict with recognised sea lanes.

### *Submarine Cables and Pipelines*

- *Internal Waters and Territorial Sea.* The state has exclusive jurisdiction.
- *Exclusive Economic Zone and Continental Shelf.* All states have freedom of laying submarine cables and pipelines, with the proviso that such actions will be done with the consent of the state which may promulgate conditions for such cables and pipelines entering its waters.

## Renewable Energies

- *Internal Waters and Territorial Sea.* The state has the exclusive right to build installations, as well as artificial islands.
- *Exclusive Economic Zone and Continental Shelf.* The state has the exclusive right to build installations and artificial islands for economic purposes, but other states retain the right to build installations required for pipelines. No state has the right to build installations and artificial islands if it will interfere with recognised sea lanes.

## The South African Development Community

The SADC comprises 15<sup>3</sup> countries from the southern tip of Africa and has been in existence since 1980. The SADC Treaty and Declaration, signed on 17 August 1992 in Windhoek, Namibia has as its main objectives the achievement of economic development and growth, peace and security, alleviate poverty, enhance the standard and quality of life of the peoples of Southern Africa and to support the socially disadvantaged through regional integration.<sup>4</sup>

### The SADC Maritime Area

The SADC has the largest maritime zone of all the Regional Economic Communities (RECs) in Africa and includes the exclusive economic zones of the islands of Mauritius, Seychelles and Madagascar, as well as the Prince Edward Island group to the southeast. The representation of the respective EEZs for each of the littoral countries of the region can be seen at figure 5.1.

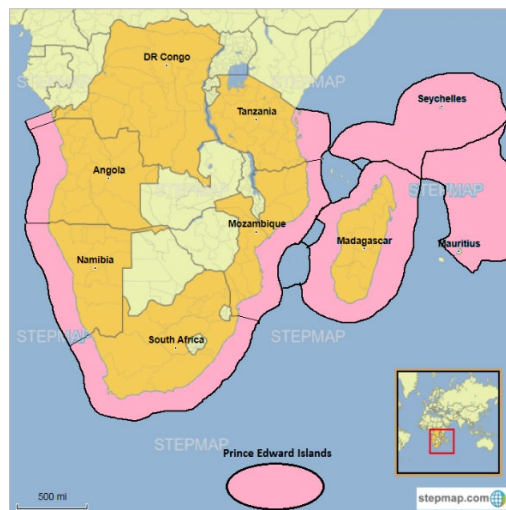


FIGURE 5.1 SADC Maritime Exclusive Economic Zones  
Source: Created in Stepmap<sup>5</sup>

### Trade Routes and Harbours

The economic success of all the SADC countries (including landlocked countries) and the well-being of their people are to a greater or lesser extent dependent on the sea and the freedom of its use to ply their trade to all corners of the earth.<sup>6</sup> Figure 5.2 depicts the major trade routes and choke points around the coast of the SADC.

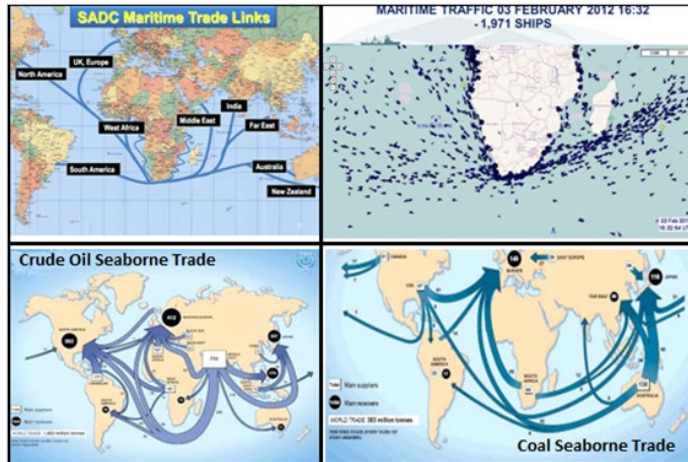


FIGURE 5.2 Seaborne Trade Routes  
Source: South African Maritime Safety Authority (SAMSA)<sup>7</sup>

The region processed 92 million tons of traffic through its ports in 2009 which is expected to increase to around 500 million tons by 2027. Between 90 and 100 tankers move round the coast each month and around 5 million tons of oil move westward around the coast each month. Around 80% of imports and exports in monetary value and around 95% in tonnage pass through the ports each month.<sup>8</sup> The region has 23 well-developed sea ports/harbours. It is understood that the location of well-developed ports, coupled with the presence of major sea lanes, contribute to the element of power that a region or country could harness to protect its own interests. The importance of the sea and the sea lines of communication to all of the countries of the region is therefore evident.

### Offshore Commerce

The offshore commercial interests of the SADC can be an important catalyst for economic growth and development in a region characterised by critical energy deficits. In 2013, South Africa, Namibia and Angola established the Benguela Current Convention (BCC), which provides for the conservation, protection, rehabilitation and enhancement

and sustainable use of the Benguela Current Large Marine Ecosystem (BCLME), worth approximately USD 54,3 billion per annum. The BCC regulates oil/gas production, marine diamond mining, coastal tourism, commercial fishing and shipping.

As far as oil and gas are concerned, Mozambique is the world's most important new source of Liquefied Natural Gas (LNG) which is second in size only to Nigeria on the African continent, while Tanzania has the third-largest reserve in sub-Saharan Africa. Angola has 13 billion barrels of oil reserves while Namibia has approximately 11 billion barrels.<sup>9</sup> The map in figure 5.3 depicts recent developments in the Southern African oil and gas sectors in the maritime domain and illustrates the growing significance of the sector and its reliance on good order at sea.

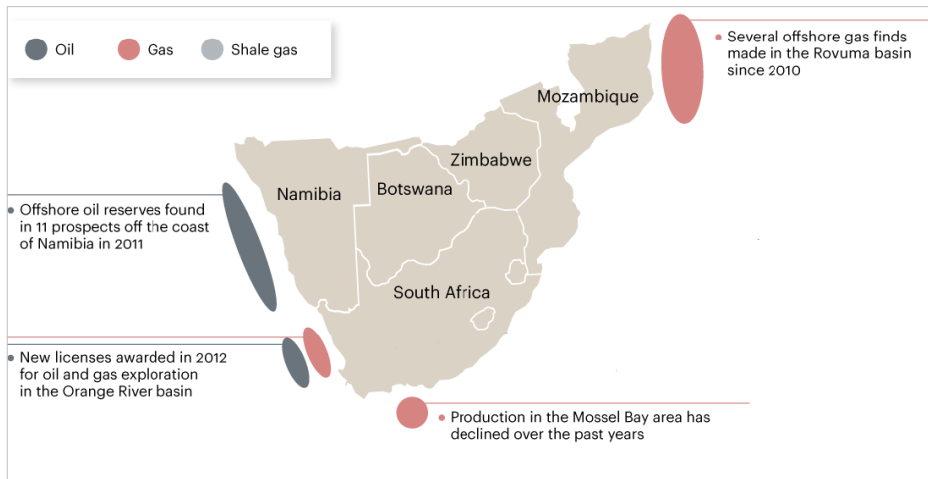


FIGURE 5.3 SADC oil and gas developments  
Source: Derived from Richard et al.<sup>10</sup>

### *Areas of Maritime Responsibility*

Although the SADC does not have a specific maritime area of responsibility, certain responsibilities are however associated with member states. SADC member states, with the exception of Madagascar and the Democratic Republic of Congo (DRC), have ratified the International Maritime Organisation (IMO) Search and Rescue Protocol of 1979, which makes provision for the establishment of an international search and rescue plan.<sup>11</sup> South Africa is assigned responsibility by the International Civil Aviation Organisation (ICAO) and the IMO for the co-ordination of Search and Rescue (SAR) in this area of approximately 17,2 million square kilometres.<sup>12</sup> The South African Navy Hydrographic Office (SANHO) is further responsible through its membership of the

IMO and the International Hydrographic Organisation (IHO) for navigational charts, hydrographic services and coastal navigation warnings for Region H and Navarea VII as depicted in figure 5.4.<sup>13</sup>

All the SADC coastal member states are signatories to the IMO Safety of Life at Sea (SOLAS) Convention of 1974 dealing with the safety of merchant ships. Under this convention, member states are responsible for, inter alia, the safety of navigation, management of the safe operation of ships, special measures to enhance maritime security, as well as the International Ship and Port Security (ISPS) Code which requires ships being provided with ship security alert systems.<sup>14</sup>

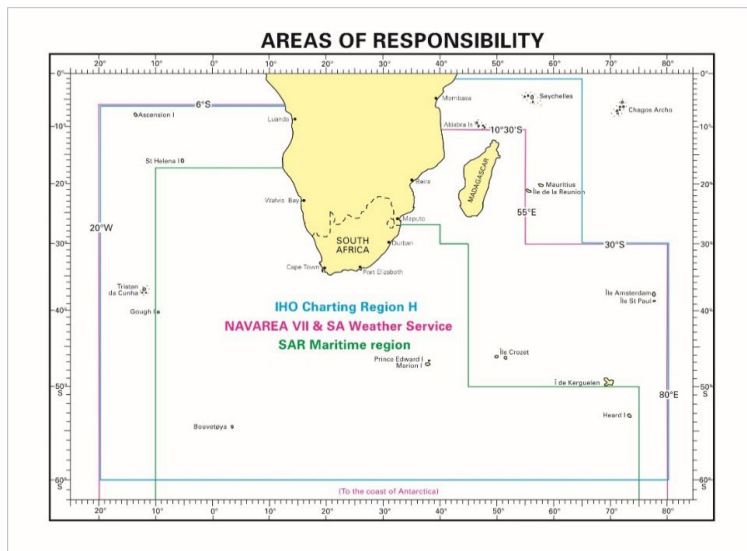


FIGURE 5.4 RSA areas of maritime responsibility

Source: SANHO<sup>15</sup>

## Threats to the Southern African Development Corporation Maritime Area

The use of the oceans is only possible if there is sufficient control to prevent the unlawful and uncontrolled exploitation of resources, which in all cases negatively influences economies. Good order at sea requires the creation of collaborative maritime security architectures to allow the conduct of free trade in a safe and secure environment. This architecture would strengthen maritime institutions so as to regulate the fishing

industry better, enhance actions against illegal acts such as piracy, pollution, smuggling, illicit trade and cross-border crime, as well as ensure safe navigation of shipping.<sup>16</sup>

### *Piracy and Armed Robbery*

Incidents of piracy or attempted piracy/armed robbery are not new to SADC waters. In 2000, there was a reported attack on a ship in Durban harbour, while attempts to board ships in the vicinities of Port Edward, as well as Port Shepstone (both in RSA waters) in 2001 and 2003 respectively have also been investigated. The absence of maritime patrolling forces will increase the likelihood of piracy incidents, but in the southern SADC area of operations, the notoriously rough seas and inhospitable coasts inhibit piracy operations.<sup>17</sup>

Towards the end of 2010, two cases of piracy off the SADC coastline were confirmed: the first an attack on a Taiwanese fishing vessel northeast of Madagascar and the second a Mozambican fishing vessel reported missing between Mozambique and Madagascar. In addition, there were two reported incidents of failed attacks by pirates close to Beira in Mozambique on 24 and 25 December 2010. The incentive for the pirates to travel further from their normal areas of operation could be found in the geography of the region – the Mozambique Channel forms a natural corridor, reducing the number of routes vessels could follow.<sup>18</sup> The implication for the SADC is that piracy is no longer a theoretical possibility; it has become a reality.

### *Maritime Terrorism*

Although terrorism in Africa is normally seen as a land-based problem, the risk to sea lines of communication, including the security of ports and harbours, remains credible and should not be ignored. In this regard, one can mention the attacks on the *USS Cole* [2000] and on the *MV Limburg* [2002] as good examples of maritime terrorism close to African soil. Maritime terrorism refers to terrorist attacks or threats of attacks against maritime assets (ships and infrastructure), using maritime platforms in attacks on land- or sea-based assets and using maritime assets for logistical support of subversive activities.<sup>19</sup>

### *Trafficking and Smuggling*

Most of the SADC countries are sources for a significant number of mostly women and children being trafficked for forced labour, agricultural labour, commercial servitude and sexual exploitation. The SADC region is prone to human trafficking due to the

vulnerabilities created by war, poverty, absence of facilities for health and education, gender and economic inequality, as well as unemployment.<sup>20</sup>

Southern Africa is geographically well positioned to receive and re-export drugs from Asia and South America, while its well-developed banking infrastructure and institutions are also contributing factors to the growing business of money laundering. Furthermore, South Africa's long porous borders, many airports, as well as growing shipping traffic provide smugglers with many options in and out of the country. The regional drug trade is closely linked to regional arms smuggling, vehicle theft syndicates, as well as ivory, diamond and gold smuggling.<sup>21</sup>

The absence of adequate patrol capabilities in harbours and coastal waters of the SADC will enhance the occurrence of human and other trafficking or smuggling.

### *Illegal Fishing/Poaching*

Fishing provides a major source of protein to the continent and any threat to the sector will be a major threat to the food security on the continent as a whole.<sup>22</sup> Statistics indicate that South Africa, Angola, Namibia and Tanzania are the major actors in this sector. While the Tanzanian growth can be attributed to the scale of the tuna industry in the Indian Ocean, the sectors in South Africa, Namibia and Angola are all positively influenced by the rich supply of fish in the cold Benguela Current on the west coast.<sup>23</sup>

The illegal, unregulated and unreported (IUU) fishing in the region has been influenced by the decimation of the Patagonian toothfish stocks in the Southern Oceans since 1998, the use of gill nets in the coastal waters of mainly Mozambique for sharks, fishing far beyond the mandate of allocated quotas and the use of illegal gear such as fine mesh nets and even dynamite. The effect of IUU fishing in the region can be felt in the economic, ecosystem and social spheres.<sup>24</sup>

Due to the nature of IUU, it is extremely difficult to obtain accurate information on any such activities. The annual loss associated with IUU in the SADC is approximately USD 50 million for Angola, USD 40 million for Mozambique and USD 37 million for Madagascar. While statistics for South Africa and Namibia are not readily available, it is agreed that the loss would be worse than in the remainder of the SADC member states.<sup>25</sup>

### *Inefficient and Insecure Commercial Ports*

Some of the identified threats to port security include: theft or hijacking of ships or service vessels, use of ships to transport illegal goods or persons, blockage of the port, use of ships alongside as weapons, and nuclear, biological or chemical attacks.<sup>26</sup> Potgieter adds that ports are very attractive to criminals due to the fact that harbours have a high concentration of very valuable goods and when control measures are scanty, the practice will be actively exploited.<sup>27</sup>

Ports remain the first point of interface between land and sea. More than 65% of attacks against ships take place while they are at anchor in or alongside any given port. It is therefore vital that security be upheld to maintain good order at sea. Dillon argues that crime against ships encompasses acts of corruption (including extortion and collusion with criminal elements) and sea robbery. Both of these activities take place while the ship remains alongside a harbour or at anchor. It is in fact these very acts that need to be curtailed in order to ensure adequate port security.<sup>28</sup>

## **Role of the South African Navy in the Region**

In order to understand the SA Navy's current role in maritime security and its dominant position in terms of capabilities and equipment, one would first have to examine the historical roots and development of the organisation.

### *Pre-Second World War*

The SA Navy was established on 1 April 1922, although naval volunteers manned coastal guns since 1861 to protect against Russian attacks which never materialised. The British "empire naval policy and cooperation" document tabled in 1921, identified Japanese aggression in the Pacific as the greatest danger for the British Empire.<sup>29</sup>

The document recommended that:

1. a light cruiser be deployed as a peacetime training ship;
2. the purchase of minesweepers and armed escort vessels;
3. the training in convoy work; and
4. repair facilities and fuel storage tanks near the Cape (Simon's Town) for its Africa Station Squadron.<sup>30</sup>



Negotiations between First Sea Lord of the Admiralty, Lord Lee and South African Prime Minister, General J.C. Smuts in 1921 resulted in termination of the annual naval contribution of £85 000 while South Africa accepted responsibility for:

- hydrographic survey of Union waters;
- establishing a seagoing permanent naval force;
- building and maintenance of fuel storage facilities;
- development of repair facilities in Simon's Town; and
- expansion of the Royal Naval Volunteer Reserve (RNVR).<sup>31</sup>

Three surplus British ships were subsequently transferred to South Africa in 1922 – one survey ship and two minesweepers converted from trawlers.<sup>32</sup>

Between 1922 and 1933, the maritime force carried out many survey operations around the coast while the minesweepers were retained until 1934 for training. During the same period RNVR bases were established in three coastal towns. The worldwide recession saw the return of the ships to the Royal Navy and a drastic reduction in naval personnel. Two officers and three non-commissioned officers were retained to continue with survey operations while the Royal Navy retained five officers, twelve non-commissioned officers and ten civilians to train and supply the RNVR (SA), with all sea training conducted in Royal Navy ships of the Africa station.<sup>33</sup>

### *The Second World War*

With South Africa's declaration of war on Germany on 6 September 1939, the country took full control of its naval forces, much to the dismay of the Royal Navy. By October 1942 German submarines began their offensive in South African waters, resulting in the sinking of 133 merchant ships and one warship in South African waters by the end of the war. During this time the South African Naval forces accounted for the rescue of approximately 400 survivors. A further twenty ships were sunk by raiders while two ships were mined. In this regard minefields were detected and cleared off the southern sea route.

On 15 December 1940 four South African ships joined the British Mediterranean Fleet as the 22<sup>nd</sup> Anti-submarine Group being used mainly as escorts for the convoys to Tobruk. The group, joined by HMSAS Protea, sunk the Italian submarine *Ondina* off Beirut on 11 July 1942. During the beginning of 1942 a further eight South African minesweepers joined the Mediterranean fleet resulting in two minesweepers lost to mines in Greek waters with only eight survivors. From October 1944-November 1945 South African

minesweepers served in Aegean and Greek waters and continued their work until the end of the war. Two South African warships served in the Pacific theatre while two Royal Navy (RN) ships in the same theatre were manned exclusively by South African sailors. During the period of the war 87 ships were commissioned into the Seaward Defence Force with 10 332 volunteers (1 436 officers and 8 896 non-commissioned officers) serving until the end of the war.<sup>34</sup>

The Royal Navy donated three Loch Class frigates to South Africa in 1944 which were subsequently manned for use by the RN if and when required. The ships served in the Western Approaches Escort Command until the end of the war. In excess of 3 000 sailors were seconded to the Royal Navy during the war. They served mostly in the Atlantic, Mediterranean, Adriatic, Pacific and Indian Oceans, as well as the convoys to Russia.<sup>35</sup>

### *Post-Second World War*

After the Second World War, the South African fleet consisted of the three Loch-class frigates, two boom defence vessels, one minelayer and eleven harbour defence launches. Eighty officers and 806 ratings were retained to constitute the naval force which was headquartered in Cape Town. Two ocean minesweepers and one corvette (converted for surveying duties) were acquired in 1947. In 1948 the naval forces moved to Durban to a base built by the Royal Navy during the war. In the period 1950-1953, two W-class destroyers were added to the South African Fleet.<sup>36</sup>

### *The Simon's Town Agreement*

The agreement has its roots in the 1885 Cape Colonial parliament act which transferred the assets of the "Simon's Bay Dock and Patent Slip Company" to the British admiralty. The RN subsequently demanded total control of the area if it was to spend significant developmental funds. Ownership of the dockyard and command of the waters of Simon's Bay were thus vested in Britain. The workshops and dry dock were constructed by 1910, which increased the status of Simon's Town as a strategic asset.

The previously mentioned 1921 Smuts/Lee agreement resulted in all land and buildings being sold back to South Africa, but specifically excluded Simon's Town with which Britain retained the right for perpetual use for naval purposes. The South African government thus accepted responsibility for landward defence of the Cape Peninsula including Simon's Town naval base and undertook to keep the base in a necessary state of readiness for imperial purposes. This should be seen in the light that the SAN was seen as an extension of the RN. In this regard both navies regarded their main task as protecting the Cape sea route.

The National Party came to power in South Africa in 1948 and immediately started focusing on the “occupation of Simon’s Town” by the RN – it was deemed unacceptable that one of South Africa’s strategic interests was owned and controlled by the British which, in fact, forced the SAN to establish its main base in Durban.

The British government’s reluctance to negotiate the agreement could be due to two reasons:

- Any such negotiations would encourage Spanish demands for Gibraltar, as well as Egypt’s demands for the Suez Canal.
- The memory of the Irish Free State remaining neutral in the war after Britain handed over three naval installations which subsequently became unavailable to the RN when required.

The Simon’s Town agreement between South Africa and Great Britain was signed on 30 June 1955 and stipulated, *inter alia* that:

- South Africa would undertake to share the defence of the Cape sea route;
- South Africa would purchase new warships from Great Britain; and
- South Africa would permit the RN to use Simon’s Town in a war, even if the country remained neutral.

The agreement thus ensured ongoing access to the dockyard and associated facilities to the RN, as well as a certain amount of command over South African maritime forces by the RN. The agreement is taken up in two formal documents:

- Agreement relating to the transfer of the Simon’s Town Naval Base.
- Agreement on defence of the Sea Routes Round Southern Africa.<sup>37</sup>

Simon’s Town was duly handed over to South Africa on 2 April 1957 and with that the SAN moved its headquarters from Pretoria. The RN headquarters were moved to Youngsfield in the Cape Peninsula. The agreement further stipulated that the following equipment would be procured for the SAN:

- One Type 15 frigate.
- Three modified Type 12 frigates.
- Ten Coastal minesweepers.
- Five seaward defence boats.

One squadron of Shackleton long-range maritime patrol aircraft and another squadron of Buccaneer strike aircraft were acquired from Britain and arrived in South Africa after 1957, complete with trained South African crews. These maritime assets assisted in deep-sea surveillance, anti-submarine patrol and air-strike backup.

The RN retained their Commander-in-Chief (South Atlantic), based in Cape Town, who remained responsible for the whole South Atlantic and purportedly had full command of all operational forces from both navies in times of war. In 1964 the British labour party won elections and barred all weapons sales to South Africa, except naval spares. Joint exercises, however, continued until 1975 when the agreement was unilaterally abrogated by Britain.

### *Further Expansion*

In 1967 South Africa purchased a fleet replenishment vessel and in 1972 a HECLA class survey vessel. The country further expanded the fleet with three DAPHNE class submarines from France during the period 1970-1971. France cancelled vessels (Type A69 corvettes and Agosta class submarines) due to a United Nations (UN) arms embargo of 1977. This resulted in the processes to purchase locally built ships. Missile boats were sourced from Israel with three built in Israel and a further six in Durban. Two minehunters were bought from Germany and a further two assembled/built in Durban. The largest ever ship to be designed and built in South Africa was launched as a support vessel in Durban in 1986.<sup>38</sup>

The above were necessitated due to a change in function from Defence HQ:

- Monitor, control and protect the interest of South Africa in territorial waters and EEZ.
- Discourage and deter any maritime aggression against RSA.
- Undertake operations supporting the achievement of objectives on land.

With the shift in military focus from seaward to landward, the SAN part of the defence budget fell from approximately 18% to less than 9% in 1979. This amounted to a reduction of around 50% of the operating budget. The sinking of one of the Type 12 frigates in 1982 signalled the end of the frigate era for the SAN.

Simon's Town remained important during this time due to increased tensions between ideologies, as well as Middle East conflicts which made the Cape sea route all the more important. On the other hand, the South African government did not fully realise the importance of maritime forces.<sup>39</sup>

### *Fall of Apartheid*

On 2 February 1990 it was announced that Nelson Mandela was to be released from prison and the African National Congress unbanned. Many saw it as the end of the SAN due to declining budgets in previous years which resulted in personnel cuts and

equipment being phased out. Projects to build submarines were cancelled even though specialised infrastructure had been developed in Durban, technology had been acquired and long-lead items were already on order. In reality the end of political isolation heralded a new era where the SAN could be used to resurrect its diplomatic function.

There was at this time also growing support from government to resurrect the blue water navy. The Minister of Defence initiated a Defence Review in 1995 to assist with and guide long-range planning. The accepted core force levels afforded the SAN the right to propose the acquisition of frigates/patrol corvettes and submarines. Approval was subsequently obtained from government to purchase new ships and submarines:

- Four MEKO A200-SAN type frigates. They arrived from 2002-2007 and were fully integrated into the SAN with weapons and operational systems fitted in South Africa.
- Four Lynx Maritime helicopters. These are operated by the South African Air Force and were handed over to the SAN in 2008.
- Three Type 209 1400 Mod RSA submarines. This was a turnkey project with vessels arriving in South Africa from 2006-2008 as fully operational vessels.

To illustrate the growing acceptance of the country and the SAN internationally, a total of 36 navies participated in Navy 75 celebrations in 1997 with 25 international ships participating and paying tribute to the commander in chief, Mr Nelson Mandela.

## South African Maritime Security Actions

South Africa's geographical position on the Cape sea route that links the Atlantic and Indian oceans, its economy relative to other SADC states, its maritime infrastructures and its capacity to deal with maritime security challenges, make the country the perfect candidate to take the initiative in responding to challenges to good order at sea in the SADC region. Responses and initiatives adopted by South Africa could therefore provide a framework for initiatives to ensure good order at sea in other SADC states.

President Jacob Zuma of South Africa announced on 19 July 2014 that the ocean economy could contribute R177 billion to the GDP of the country. He indicated the importance of the ocean as an economic potential and highlighted four priority growth sectors: marine transport and manufacturing activities, offshore gas and oil exploration, aquaculture and marine protection services including ocean governance. He announced Operation Phakisa, which would aim to develop an incremental and integrated approach to planning, monitoring and execution of ocean governance and enforcement in the next few years.<sup>40</sup>

### *The notion of an 'ocean territory' (South Africa's 10<sup>th</sup> province)*

Deacon argues that the notion of a littoral state having ocean territory in addition to its terrestrial territory is quite reasonable because, in essence, the United Nations Convention on the Law of the Sea (UNCLOS) defines internationally recognised borders within which the coastal state has jurisdiction superior to other states. He therefore contends that, in essence, South Africa has a '10<sup>th</sup> province' that must be integrated into the broader South Africa along with the other nine provinces.<sup>41</sup> This implies proper governance of such a territory, with all its ramifications of policy, strategies and planning. It also implies the development of appropriate structures and organs to govern the ocean territory properly. The idea of governing the maritime zones of SADC littoral states as ocean territories would assist such states to grow and develop their maritime sectors more effectively and efficiently.<sup>42</sup>

### *Maritime border safeguarding*

The South African Defence Review 2014 states: "South Africa's borders and strategic installations will be safeguarded<sup>43</sup> by the Defence Force in conjunction with other Departments." It further states, "Defence will assume full responsibility for land, air and maritime border safeguarding" and that "[t]his will be pursued with Defence leading all collaborative efforts concerning safeguarding on the border-line<sup>44</sup> and the immediate rear areas".<sup>45</sup> This is a fundamental departure from the Defence Review of 1998, in that in this latter review, the responsibility for border safeguarding was allocated to the South African Police Service.

Maritime border safeguarding is conducted in the SANDF under the auspices of Operation Corona, which plans and conducts land, sea and air border-line safeguarding as a component of the defence of the territorial integrity and sovereignty of the RSA, the domestic layer of defence in the layered defence concept of the SANDF.<sup>46</sup> The maritime border safeguarding concept for the short and medium term focuses on deterrence and the enforcement of state authority at sea from the territorial sea out to the exclusive economic zone and later to the extended continental shelf. This will be done through the ad hoc deployment of naval and air assets supported by Maritime Domain Awareness (MDA). The concept also sanctions the ad hoc deployment of maritime surface and air assets into adjacent waters of Namibia and Mozambique during approved multinational operations to extend deterrence beyond South African waters and to enhance MDA.<sup>47</sup>

Although the border safeguarding concept prescribes collaboration with other government departments and agencies, many academics and security practitioners believe that mere co-ordination between departments and agencies is not enough

and they have been calling for a more integrated approach to border safeguarding. Colonel Anton Grundling from the SANDF's Joint Operations Division and Duarte Goncalves from the Council for Scientific and Industrial Research (CSIR) have recently proposed a 'whole of government approach' to border safeguarding, with an integrated legal framework to support integrated planning for border safeguarding.<sup>48</sup> The recently established Border Management Agency, to facilitate co-ordination between government departments, seems to be a step in the right direction.

### *Maritime Domain Awareness*

MDA is a crucial component in the concept for maritime border safeguarding and maritime defence. To this end, the SA Navy is in the process of establishing Maritime Domain Awareness Centres (MDACs) in Durban and Cape Town respectively. These MDACs will eventually link with Maritime Security Centres (MSCs) that are being established in Tanzania and Mozambique. MSCs are also being established in Angola and Namibia, but are not yet linked while Botswana, Lesotho, Malawi, Zambia and Zimbabwe have established operational frameworks to facilitate the necessary links with MDACs and MSCs.<sup>49</sup>

Various other government departments and agencies in South Africa possess databases, information centres and coordination facilities that are relevant to MDA. These departments and agencies share information to some degree. Although the MDACs, MSCs and government departments and agencies are linked and share information, there is no formal process to fuse the information and data, or to do integrated analyses regarding possible threats and risks.

### *Tripartite Maritime Security MOU*

A memorandum on maritime security cooperation between South Africa, Mozambique and Tanzania was signed in February 2012 in an effort to secure sea borders and tackle the problem of maritime piracy. It was believed that this effort would also reduce trafficking and illegal fishing. It allowed for multifaceted maritime security operations such as information sharing, surveillance, conducting joint military exercises and operations, patrolling, hot pursuit, arrest and search and seizure.<sup>50</sup> Tanzania withdrew from the MOU around January 2013 while Mozambique continued to provide personnel onboard SA Navy ships involved in Operation Copper.<sup>51</sup>

## *Search and Rescue*

A multilateral agreement between South Africa, Madagascar, Comoros and Mozambique, signed in 2007, makes provision for cooperation in Search and Rescue (SAR) in areas adjacent to the coast.<sup>52</sup> The main Maritime Rescue Coordination Centre (MRCC) for Navarea VII is in Silvermine with sub-centres in Walvis Bay, Durban, Dar es Salaam and the Seychelles. The responsibility regarding SOLAS (as discussed previously under the heading “Areas of Maritime Responsibility”) is associated with the Department of Transport (SAMSA) in South Africa with the department having a permanent seat at the IMO. There is however no coordination with the SANHO. It would seem that the regional coordination is problematic while international cooperation is very successful.<sup>53</sup>

## *Promoting Safe Passage*

As a member of the IHO since 1951, the SANHO has been tasked with the charting of region H, contributing to charting for region M (Antarctica) and coordination of Navarea VII maritime safety information (see figure 5.4). South Africa drew up a Hydrographic Cooperation Plan for the Standing Maritime Committee (SMC) of the SADC, which is currently in force and urged member states to apply for membership of the IHO.<sup>54</sup> The Southern Africa and Islands Hydrographic Commission (SAIHC) was established in 1996 with SADC members being members or associate members. The aim of the SAIHC is to improve hydrography in the region with the focus on capacity building. In the SADC maritime area, South Africa produces hydrographic information for Namibia and its own shores, while Portugal covers Angola, France covers Madagascar, India covers the Seychelles and the UK covers Mozambique and Tanzania. Mozambique has a very small hydrographic office, but has no production capability.<sup>55</sup>

## *Exercises, Operations and Symposia*

An exercise called Interop East/West is held annually along the coast of Africa. It is initiated by South Africa while all SADC member states are encouraged to send representatives. The exercise focuses on search and rescue, ship safety exercises, seamanship and joint and multilateral cooperation. Exercise Good Tidings, an exercise in riverine operations, was held in Malawi in September 2011 with further similar SADC-sanctioned exercises scheduled in other member countries annually. The SA Navy annually participates in Exercises Ibsamar (India, Brazil and South Africa) and Atlasur (South Africa, Argentina, Brazil and Uruguay). These exercises facilitate interoperability, enhance readiness and develop doctrine, tactics and operating procedures. Plans are at an advanced stage to invite navies on the African west coast to Exercise Atlantic Tidings, which would run parallel with the aforementioned exercises. As part of the SMC, the participating SADC



countries discuss force support cooperation plans, naval training cooperation plans, hydrographic cooperation plans and naval coordination and guidance of shipping cooperation plans.<sup>56</sup>

In 2001 the SAN took part in Operation LARIAT assisting the Australian government with the interception of the fishing vessel *South Tommy* which was fishing illegally in Australian waters and was the subject of hot pursuit by Australian authorities. A similar operation in 2003 saw the trawler *Viarsa* intercepted and arrested. In 2004 the SAN took part in Operation KATUSHA to provide logistic support and protection during Haiti's 200<sup>th</sup> anniversary of independence.

The SAN took part in reviews in India, Brazil and Nigeria, as well as Operation VICTORY, the Trafalgar 200 review at Isle of Wight in 2005. In 2007 the first of class frigate SAS AMATOLA deployed to the UK for Basic Operational Sea Training (BOST) with Flag Officer Sea Training (FOST).<sup>57</sup>

The Seapower for Africa Symposium (SPAS) concept was initiated by Chiefs of Navies of Ghana, Kenya, Nigeria and South Africa at an International Sea Power Symposium in 2003 in Rhode Island, USA. They identified a requirement for a maritime platform to raise and discuss maritime issues common to Africa. The 1<sup>st</sup> such symposium was held in Cape Town in August 2005 where 23 African nations attended with subsequent symposia held in Nigeria and planned for the rest of Africa. The common themes discussed at these symposia include:

- Charting Africa's maritime zones.
- Piracy and maritime crime off the coast of Africa.
- Patrol & control Africa's vast maritime hydrocarbon resources.
- Controlling Africa's maritime choke points.
- Enhancing African regional maritime co-operation: areas of scientific and technology support.
- Maritime, inland waters and riverine disaster management.

The SPAS identified a need for structured continental and regional co-operation to address matters of maritime security and governance, the need to maximise potential areas of continental and regional co-operation, the requirement to establish continental and regional agreements, arrangements and capabilities, the inclusion of all landlocked countries in deliberations and the need to capacitate and support the Maritime Office of the African Union (AU).

In order to realise the above themes, the SPAS identified the need for the generation of a comprehensive maritime security policy for Africa, the recognition of the importance of collective continental and regional ownership and support of all issues pertaining to maritime governance, the requirement for the harmonisation of laws, policies and institutions to facilitate efficient co-operation and collaboration in pursuit of ensuring maritime security continentally and regionally and the need to explore the legal framework as a method of providing mechanisms of co-operation. The overriding obligation was placed on all African countries to bring to the attention of their people and their governments the critical importance of the maritime domain to their economic well-being.<sup>58</sup>

## Conclusion

South Africa has started to realise the importance of the ocean economy and has taken significant steps to harness its full potential. The crux of the matter is that the use of the ocean for its vast economic potential is dependent on good order at sea and this is only possible through a collaborative, comprehensive approach to (maritime) security.

The threats to the SADC maritime area remain vast and, in most instances, underreported and unregulated. The modern, wide-ranging and complex maritime security environment demands a pro-active, preventative, comprehensive and considered response to a very broad spectrum of security challenges. In this regard, the maritime agenda has become a significant part of the security landscapes of South Africa, the SADC and Africa.

The South African Navy has been the dominant maritime force in Sub-Saharan Africa for close to a century. Its development, current status and structure can be explained by its historic involvement in global and colonial maritime events while the signing of the Simon's Town agreement resulted in it taking responsibility for vast maritime areas and laid the foundation for a world-class maritime force. Its modern assets are utilised to play a meaningful role in maintaining and ensuring good order at sea in its maritime domain and beyond.

## ENDNOTES AND REFERENCES

1. UN General Assembly, Convention of the Law of the Sea. 1982. [Online]: <http://www.refworld.org/docid/3dd8fd1b4.html> [Accessed 15 April 2017].
2. Gibson, J. 2009. Maritime security and international law in Africa. Institute for Security Studies: *African Security Review*, 18(3).
3. The SADC comprises Angola, Botswana, the Democratic Republic of Congo (DRC), Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, the United Republic of Tanzania, Zambia and Zimbabwe.
4. Southern African Development Community (SADC). 1993. *Declaration and treaty of the Southern African Development Community*. Gaborone: Printing & Publishing Company Botswana. pp. 4-5.
5. Created in Stepmap.com by the author. <https://www.stepmap.com/map/sadc-littoral-states-1808514>. [Accessed 26 July 2018].
6. Higgs, R.W. 2013. Promoting maritime security. *Keynote address on the occasion of the Conference on BRICS and Africa: A Partnership for Sustainable Development*, South African Institute of International Affairs, Johannesburg, 13 November.
7. Mokhele, T. 2013. Towards an integrated maritime agenda. Presentation notes from an Eastern Cape Ports and Maritime Conference, Port Elizabeth.
8. South African Navy. *Role of the SA Navy*. 2013. [Online]: <http://www.navy.mil.za/aboutus/role/> [Accessed 5 April 2014].
9. Southern Africa Research and Documentation Centre (SARDC). 2011. Energy in southern Africa. *SARDC: Southern Africa Today*. [Online]: [http://www.sardc.net/sadcenergy/SADC\\_Energy\\_Bulletin\\_6.pdf](http://www.sardc.net/sadcenergy/SADC_Energy_Bulletin_6.pdf) [Accessed 15 April 2014]. pp. 8-9.
10. Richard, D.; Alberich, J.; Wilczynski, H.; Sprott, M.; Plaizier, W. & Pierce, J. 2013. Southern Africa's oil and gas opportunity. AT Kearney. [http://www.atkearney.com/oil-gas/ideas-insights/article/-/asset\\_publisher/LCcgOeS4t85g/content/southern-africas-oil-and-gas-opportunity/10192](http://www.atkearney.com/oil-gas/ideas-insights/article/-/asset_publisher/LCcgOeS4t85g/content/southern-africas-oil-and-gas-opportunity/10192) [Accessed 8 July 2014].
11. SARDC, 2011, op. cit., pp. 8-9.
12. Government of South Africa. Act 44 of 2002: South African Maritime and Aeronautical Search and Rescue Act. *Government Gazette*, 451/24248. Pretoria: Government Printing Works.
13. Kampfer, A. (Hydrographer SA Navy). Interview. 11 April 2014.
14. International Maritime Organization (IMO). 2014. *Status of conventions*. [Online]: <http://www.imo.org/About/Conventions/StatusOfConventions/Pages/Default.aspx> [Accessed 15 April 2014].
15. Published with permission from the hydrographer, South African Navy, Capt. A Kampfer, South African Navy Hydrographic Office, April 2014.
16. Stead et al., op. cit., p. 8.
17. Fouché, H. 2009. Piracy: The African experience. In: T.D. Potgieter & R. Pommerin (eds.), *Maritime security in southern African waters*. Stellenbosch: AFRICAN SUN MeDIA. 84-86.
18. Germishuys, J. (SO1 Maritime Planning at the South African Joint Operations HQ in Pretoria). Interview. 7 April 2014.

19. Chalk, P. 2008. *The maritime dimension of international security: Terrorism, piracy and challenges for the United States*. RAND Project Air Force. Santa Monica, CA: RAND Corporation. pp. 2-3.
20. Southern African Development Community (SADC). 2009. *10 year SADC strategic plan of action on combating trafficking in persons, especially women and children (2009-2019)*. SADC Secretariat. 1-2.
21. Oosthuyzen, G. 1997. Illegal narcotics trafficking in southern Africa. *Strategic Analyses*, 20(2):271-279.
22. Stead et al., op. cit., pp. 19-20.
23. Purves, M. 2008. Illegal, unreported and unregulated fishing and maritime security in southern Africa. In: T.D. Potgieter & R. Pommerin (eds.), *Maritime security in southern African waters*. Stellenbosch: AFRICAN SUN MeDIA. pp. 113-116.
24. SADC. 2008. *Study and analysis of IUU fishing in the SADC region and an estimate of the economic, social and biological impacts*, pp. 6-7.
25. Ibid.
26. Khwela, C. The importance of port security to maritime security. In: T.D. Potgieter & R. Pommerin (eds.), *Maritime security in southern African waters*. Stellenbosch: AFRICAN SUN MeDIA.
27. Potgieter, T. 2012. *Maritime security in the Indian Ocean: Strategic setting and features*. Institute for Security Studies, 236:8.
28. Dillon, D. 2005. Maritime piracy: Defining the problem. *SAIS Review* XXV/1:157-159. <https://doi.org/10.1353/sais.2005.0005>
29. Stockton, B (ed.). 1997. *A Navy for Three Oceans*. Cape Town: BP Southern Africa. p. 2.
30. Bennet, C. & Soderlund, A. 2008. *South Africa's Navy*. SA Navy: Pretoria. pp. 15-17.
31. Stockton, 1997, op. cit., p. 2.
32. Bennet, 2008, op. cit., pp. 15-19.
33. Stockton, 2006, op. cit., p. 2.;  
Bennet, 2008, op. cit., p. 17.
34. Stockton, 2006, op. cit., p. 8.;  
Bennet, 2008, op. cit., pp. 21-25.
35. Stockton, 2006, op. cit., p. 8.
36. Ibid., p. 10.
37. Bennet, 2008, op. cit., pp. 39; 46
38. Stockton, 2006, op. cit., pp. 11, 12.
39. Bennet, 2008, op. cit., pp. 35; 41.
40. Anonymous. Ocean can contribute R177bn to GDP – Zuma. *Fin24*. 19 July 2014. [Online]: <http://www.fin24.com/Economy/Ocean-can-contribute-R177bn-to-GDP-Zuma-20140719> [Accessed 20 July 2014].
41. Deacon, H.D. 2006. Maritime transport in context of the maritime sector in South Africa. In: *Proceedings of the 25<sup>th</sup> Southern African Transport Conference (SATC 2006)*, Pretoria. [Online]: <http://repository.up.ac.za/bitstream/handle/2263/6069/033.pdf?sequence=1> [Accessed 9 May 2014]. p. 170.

42. Ibid.
43. Safeguarding South Africa includes its people, territory, islands, territorial waters, exclusive economic zone, extended continental shelf, vital interests, resources and critical infrastructure.
44. The border line does not include ports of entry and border posts. These remain the responsibility of other departments.
45. Republic of South Africa Department of Defence, op. cit., Chapter 6.
46. Hlatshwayo, B. 2011. *Operation CORONA – Border safeguarding*. Presentation at the 2nd Annual DefenceWeb Border Control Conference, Pretoria, slide 10.  
[Online]: <http://www.defenceweb.co.za/media/jukebox/Border%20Control%202011/Barney%20Hlatshwayo.ppsx> [Accessed 15 April 2014].
47. Ibid., slide 35.
48. Martin, G. 2013. Integrated approach needed for border security – experts. *DefenceWeb*. [Online]: <https://bit.ly/2UU0Pf5> [Accessed 15 April 2014].
49. Higgs, R.W. 2014. *Prospects for achieving maritime security in SADC*. Presentation at the Institute for Security Studies, Pretoria, 11 April. p. 9. Personal notes furnished to author.
50. Otto, L. 2012. *Mozambique's security cooperation: Protecting the maritime borders*. South African Institute of International Affairs. [Online]: <http://www.saiia.org.za/opinion-analysis/mozambiques-security-cooperation-protecting-the-maritime-borders> [Accessed 15 April 2014].
51. Martin, G. 2014. Operation Copper now only with South Africa and Mozambique. *Neptune Maritime Security*. p. 20. [Online]: <http://www.neptunemaritimesecurity.com/operation-copper-now-sa-mozambique/> [Accessed 15 April 2014].
52. South African Maritime Safety Authority (SAMSA). *Sea watch and response overview*. [Online]: <http://www.samsa.org.za/service/rescue-co-ordination> [Accessed 15 April 2014].
53. Kampfner, 2014, op. cit.
54. Republic of South Africa Department of Defence. 2014. *The South African Defence Review 2014*. Chapter 9: 8.1, 8.2. [Online]: <http://www.gov.za/documents/detail.php?cid=402524> [Accessed 1 June 2014].
55. Kampfner, 2014, op. cit.
56. Standing Maritime Committee of the ISDSC. 2012. *Minutes of the 18<sup>th</sup> meeting of the Work Group to the Standing Maritime Committee (SMC) of the Interstate Defence and Security Committee (ISDSC)*. Durban. [Online]: [http://www.navy.mil.za/SMC/2012/Minutes%20of%2018th%20Meeting%20\(English\).pdf](http://www.navy.mil.za/SMC/2012/Minutes%20of%2018th%20Meeting%20(English).pdf) [Accessed 15 April 2014].
57. Bennet, 2008, op. cit., pp. 63-65.
58. Teuteberg, B.H. 2010. *Africa's Strategy for Maritime Security – A SA Navy Perspective*. *Presentation Notes*, Pretoria, 2010.



# PART 4

Terrain

# Terrain Negotiability

## PROPOSING A GEOGRAPHIC INFORMATION SYSTEMS (GIS) MODEL FOR THE SOUTH AFRICAN ARMY



Antonio Garcia 

### Introduction

The ability to negotiate various types of terrain is essential for army landward-based operations. During offensive ground operations the commander and staff have to determine which routes to take as part of the advance and attack. While the commanders at the respective levels consider the strategic, operational and tactical situation the engineer officer has to determine the trafficability/negotiability of the terrain throughout the theatre of operations. This terrain negotiability data is presented to the commander who then uses it as one of the aspects for developing their operational plans.

The process of determining terrain negotiability within the South African Army (SA Army) is principally done by the commander and staff and this process involves the manual and often haphazard calculation of trafficable areas on overlays which are superimposed on hardcopy maps. With the advent of ever-increasing technological



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sophistication there is a growing need and opportunity for GIS-based negotiability mapping.<sup>1</sup> The aim of this chapter is to propose a GIS-based terrain negotiability model for the SA Army.

Terrain negotiability refers to the ability of vehicles to move across off-road terrain. The USA and certain other countries describe this as terrain trafficability (negotiability and trafficability will be used interchangeably). The issue of terrain negotiability is of central importance to the military and, more specifically, the army as it applies directly to the mobility of ground forces. Terrain trafficability is inextricably linked to the military concept of mobility which can be defined as “the ability to move freely and rapidly over the terrain of interest to accomplish varied combat objectives”.<sup>2</sup>

Mechanised vehicles are vital as they provide mobility to the military and landward-based operations. The identification of negotiable terrain for the movement of these vehicles is significant as the categorisation of terrain delimits and indicates the scope available and feasible for mechanised movement. The army’s ability to move forces over off-road terrain at the right time, to the right location with the correct supplies is central to military operations.<sup>3</sup> The aim of this chapter is to propose a terrain negotiability model using GIS and to determine the terrain components required to model off-road terrain maneuverability.<sup>4</sup> Modern studies in South African military geography highlight the importance of mapping support, terrain negotiability and the engineer officer’s role in creating the required terrain products to execute successful military operations.<sup>5</sup> This chapter builds on this discussion by expanding the debate to include the components necessary to model terrain negotiability.

Landward-based military operations begin with the commander receiving orders from the higher headquarters. These military orders often identify objectives which are to be attained within a given area of operations. The area of operations refers to the geographical setting in which the operation is to take place. Upon receipt of the orders, the commander in question goes through a process of planning and reconnaissance which culminates in the writing of further operational, fragmentary, or other orders which essentially becomes a blueprint for the mission. The process of receiving orders and creating orders in the South African military forms part of what is referred to as “deployment drills”.

The primary considerations when compiling an operational plan for land-based operations include the identification of objectives, the allocation of resources and the analysis of terrain in the area of operations. During the planning process, the combat



engineer staff officer is responsible for terrain analysis throughout the brigade planning process. Terrain analysis can be defined as “the process of interpreting a geographical area to determine the effect of natural and man-made features on military operations”.<sup>6</sup>

Within the operational planning cycle the commander and staff create a map or series of maps with terrain negotiability overlays that form the basis of where mechanised forces can move and the limitations to such movement in the physical environment. This process delimits the area of mobile operations. The classification of terrain is thus of fundamental importance to the military as it demarcates the limits of mobile operations.<sup>7</sup>

The engineer officer is regarded as the terrain expert whose responsibility it is to advise the commander on geographical matters at the different levels of war.<sup>8</sup> The military engineer conducts terrain studies and analyses with the purpose of determining trafficability of a given geographic area.<sup>9</sup> The trafficability study should indicate negotiable, partially negotiable and non-negotiable terrain through the use of overlays. These overlays may take the form of plastic overlays in the case of a hardcopy map, where the overlay is placed and annotated on a map, or through the computerised production of a negotiability map. Quite often in conventional operations and force training, terrain negotiability has been determined in a haphazard fashion by the officer in charge in conjunction with his supporting staff officers (engineer and intelligence/geo-spatial officers). The terrain study, as an intelligence product, is intended to be a thorough study of terrain in the operational theatre. This analysis is produced by the engineer terrain intelligence staff officer who falls under the G2 (army/division/brigade intelligence staff officer) or relevant intelligence/geo-spatial staff compartment with the purpose of informing the commander of the terrain characteristics in a given area.<sup>10</sup> The engineer officer may also be placed under the G3 (army/division/brigade operations staff officer) or a separate engineer section depending on the mission type and structure.<sup>11</sup> The GIS capability could be under the army, division, brigade, or battalion headquarters depending on the type of mission.

The engineer officer makes use of terrain studies and physical reconnaissance to determine the negotiability of terrain. There are several sources of terrain information which can be processed into intelligence. The use of hardcopy maps and overlays have several limitations and disadvantages which include: the possibility of being out of date, the size and scale of the map which is fixed, unlike a digital map where the zoom function can be applied; and maps that are annotated manually can become cluttered and certain elements of data could be accidentally negated.<sup>12</sup>

At present there is no digital terrain trafficability model used in South Africa's military as is done in other organisations such as the NATO Reference Mobility Model (NRMM). The USA military formerly used the Condensed Army Mobility Model System (CAMMS).<sup>13</sup> Trafficability maps can be created through the computing of various terrain data which results in the display of go and or no-go areas.<sup>14</sup> The use of GIS modelling to determine terrain negotiability/trafficability ensures effective terrain analysis, as well as a more scientific and objective method of evaluating geographic spatial dynamics in terms of terrain negotiability.<sup>15</sup> Terrain analysis should address vehicle trafficability with specific reference to the following factors: slope, vegetation, soil and hydrology.<sup>16</sup> This chapter focuses on off-road mobility and will not consider the enemy threat, obstacles and/or enemy operations.

GIS facilitates terrain analysis by producing negotiability maps using current geospatial data which may expedite the decision-making process of commanders. The speed of planning operations is of great consequence in the modern military context.<sup>17</sup> GIS modelling involves creating spatial representations of natural and other phenomena so as to better understand them.<sup>18</sup> A GIS model can thus represent spatial features, including the different types of terrain which includes soil, slope, vegetation and the influence of moisture.

## Background

Modern military operations are highly dependent on mechanised vehicles and these vehicles are, in turn, only efficient on terrain which is trafficable. Modern landward-based operations in the SA Army, for the most part, take the form of peace missions in sub-Saharan Africa. These operations may be mandated under the African Union, United Nations (UN) under Chapter 6 or 7 of the UN Charter, or other peacebuilding or post-conflict reconstruction missions. Thus, it is important to understand the terrain in the African battle space, especially given the large and diverse area of operations. The importance of terrain in modern South African military history and geography has been highlighted in a number of contemporary studies which range from the importance of water, the modification of terrain for tactical purposes, access and trafficability and environmental health amongst other important themes.<sup>19</sup>

Terrain intelligence can be applied on strategic, operational and tactical levels and was historically utilised in the planning of war in the 20<sup>th</sup> century.<sup>20</sup> The impact of terrain intelligence and terrain trafficability analysis on the military is perhaps best summarised by the First World War motorised armoured car commander, W. Whittal, who claimed "the analysis and classification of terrain is not always so as to find an alternate route but

rather to know the time limitations of a given route”.<sup>21</sup> Military history and the history of military geography can provide some clues as to the importance of terrain analysis within the planning of military operations.

The German military started the First World War with little appreciation for the importance of military terrain studies. As the conflict progressed, the Germans started encountering problems with water supply and mine warfare and the need for military geological and geographical studies became increasingly important. German geologists developed studies and maps to address water supply and soil studies to determine the feasibility of military movement.<sup>22</sup> During the Second World War, with lessons clearly learned, Germany employed a unit of military geographers and geologists who were exclusively dedicated to terrain studies and research during the planning stages of offensive operations. These military geology units gathered terrain intelligence on various geographical factors including off-road terrain trafficability.<sup>23</sup> The importance of geographical studies in combat was not lost on the British, French and American forces, who also promoted terrain studies so as to better plan and conduct operations during the First and Second World Wars.

By the end of the First World War the French and British engineers had developed tank mobility maps which indicated areas where tanks could move freely, with some difficulty, as well as areas where tank movement was restricted.<sup>24</sup> Furthermore, the static operations on the Western Front led to a need for the development of water supply systems. British engineers employed geologists and hydrologists and conducted extensive borehole drilling to provide drinking water for the fighting forces.<sup>25</sup> During the Second World War the USA conducted geological research to determine areas suitable for amphibious landings. The USA and British militaries have continued to conduct terrain trafficability studies and analyses to suit their operational needs.<sup>26</sup>

Similarly, the South African military developed its geographical and cartographic support capability during the Angolan War. Terrain trafficability was initially introduced during the 1970s where civilian scientists were deployed to conduct terrain analyses in southern Angola. Their research soon confirmed a larger need for negotiability analyses and a trafficability section was included within the South African military survey capability.<sup>27</sup> This negotiability analysis is used as the base for the conceptual negotiability model proposed in this chapter. The idea is to build on the old system by introducing new technologies and processes. Terrain components and characteristics will always be an important consideration in future military operating concepts.<sup>28</sup> This may apply to conventional operations, guerilla/counter-insurgency operations, operations other than war (including peacekeeping) or peacebuilding, humanitarian efforts and disaster relief.

The application of terrain studies is complex, and as such, the term “complex terrain” has been coined and is defined as “the environment shaped by physical, human and informational factors that interact in a mutually-reinforcing fashion”.<sup>29</sup> Insurgents often use complex terrain to their advantage whereas conventional forces aim to, within reason, avoid complex terrain.<sup>30</sup> The physical aspect of complex terrain may include urban centres, surface and subsurface terrain components amongst other geographical aspects.<sup>31</sup> This chapter, for the most part, addresses the physical environment which could be applicable to the sub-Saharan operating environment. The different terrain types in sub-Saharan Africa are the future battlegrounds of the South African Defence Force in the African battlespace.<sup>32</sup>

The type of terrain in the different theatres of operations may vary. In the case where there are not established roads within the combat and communication zones<sup>33</sup> and between the support and fighting echelons, the commander and staff must be aware of the impact of the climate on the axes and main supply routes. Terrain negotiability is always fundamentally influenced by the rainy/wet season, where applicable.<sup>34</sup> Within the sub-Saharan environment, especially within the tropics, a commander has to consider the wet versus dry seasons and its impact on the various axes of advance.<sup>35</sup> Terrain negotiability can be adversely affected by a prolonged rainy period which may in turn influence mobility and surprise.

Many militaries across the world use some form of testing for terrain negotiability. The USA military has various field manuals that allude to terrain trafficability such as FM 30-10 (Terrain Intelligence) and FM 5-430-00-1 (Design of Roads, Airfields and Heloports).<sup>36</sup> FM 30-10 specifies the importance of terrain analysis and the identification of different land forms, soils, natural obstacles and hydrology as this data forms the basis of terrain intelligence.<sup>37</sup> The proposed GIS model may be optimised by the use of current remotely sensed data. A GIS model simulates reality through the recreation of geographic spatial features or the relationship between physical environmental aspects. There are various types of models including descriptive and prescriptive. Descriptive models could indicate a given terrain aspect such as soil which could then be graphically represented. Prescriptive models offer a solution to a problem posed. For example a navigational map could offer possible routes to a set destination using a least cost path analysis.<sup>38</sup>

## Tools for Geographic Information Systems Modelling

A GIS includes in its definition computers and information systems, software, spatially referenced data and the wide processes of management and analysis tasks.<sup>39</sup> The analytical and processing tasks of a GIS should be applied to the spatial data relevant to the off-road trafficability model. A GIS “is a computer system for capturing, storing, querying, analysing and displaying geospatial data”.<sup>40</sup> A GIS is “capable of compiling large multi-layered databases, interactively analysing and manipulating those databases and generating and displaying resultant thematic maps and statistics to aid military engineering decisions”.<sup>41</sup>

The slope of a terrain feature has a serious impact on its negotiability. Vehicles have a limit as to the maximum angle of inclination which they can climb. During the wet season, as a general rule, vehicles should not attempt to climb high ground with a slope of more than 30%.<sup>42</sup>

Digital elevation models (DEMs) are mathematical representations of the earth’s surface that emphasise the topographical and relief aspects. They greatly impact terrain modelling in GIS.<sup>43</sup> DEMs can be made from remotely sensed data that are sourced, geo-referenced, projected and mapped for terrain trafficability using a GIS. There is much research on the close relationship between soil and slope. The combination of moisture and slope can have a huge impact on the trafficability of vehicles.<sup>44</sup> The use of a DEM with a high resolution is important so as to be able to identify the slope and angle of features.<sup>45</sup>

GIS models are constructed for practical purposes in both civilian and military contexts. Such models can be classified as “a priori” and/or as “posteriori”. In the case of an “a priori” model it refers to where there is no established theory and “posteriori” refers to a case or study for which there is an established theory.<sup>46</sup> This chapter proposes a “posteriori” negotiability model, but focuses it on the South African military context.

Terrain models are used for tactical, operational and/or strategic planning.<sup>47</sup> On the strategic level, terrain trafficability could pertain to the feasibility of conducting military operations in a given country whereas on the operational level it could refer to choosing lines of advance or determining main supply routes. On the tactical level terrain trafficability demarcates where mechanised forces can move so as to achieve their battle objectives.<sup>48</sup>

The proposed GIS terrain negotiability model should serve to identify areas and delimit spheres of operations, whereas the command initiative and the decision remain with the commander and staff. Once the trafficability of the terrain in the area of operations has been established, the commander has to select the advance routes. The Finnish Defence Force developed a military terrain analysis application for off-road mobility which makes use of four spatial variables in its analysis, namely; soil, slope, vegetation and frost.<sup>49</sup> The USA military battle simulation researchers employ a GIS that identifies the off-road fastest route using the mathematical shortest path method.<sup>50</sup> This type of model is something that the South African military should perhaps consider for the future.

The spatial dynamics and data sets used in the development of terrain trafficability maps are relative to the environmental conditions and area of operations of country or territory in question. For example, a dataset for trafficability in South Africa or sub-Saharan Africa would not necessarily be applicable for trafficability in Iceland. Virrantaus's trafficability study includes soil type, slope and vegetation and allocates each aspect a value from 1-7 that designates the trafficability feasibility.<sup>51</sup>

Korean researchers used mathematical equations to determine approach routes and areas which could be mapped in terms of trafficability. The basic data used for the terrain analysis include slope, soil, elevation, land cover and major rivers. The terrain negotiability gives an answer as a percentage.<sup>52</sup>

Terrain trafficability is determined by the relationship between the physical landscape and the ability of a given vehicle to traverse various types of terrain. Suvinen alludes to certain key properties of the vehicle which critically influence trafficability such as: weight, power transmission, power of the engine, number of wheels and the size and dimensions of the wheels.<sup>53</sup> These mechanical factors can be analysed in relation to the physical properties of the terrain. Figure 6.1 presents an equation which requires the input of values for the terrain and vehicle in question and determines their spatial relationship through identifying limits.

$$\text{Cost distance} = \text{Surface distance} * \text{Vertical factor} * ((\text{Friction(a)} * \text{Horizontal factor(a)} + \text{Friction(b)} * \text{Horizontal factor(b)})/2).$$

Vertical factor = slope resistance, kN.

Horizontal factor(a) = lateral inclination, go/no-go situation

Horizontal factor(b) = sum of horizontal resistance forces, moving direction, kN.

FIGURE 6.1 Cost analysis equation for mechanical and terrain factors<sup>54</sup>

GIS modelling and terrain trafficability analysis is designed to support military operations. The USA military focuses much research on the Intelligence Preparation of the Battlefield (IPB) and incorporates terrain analysis and a Modified Combined Obstacles Overlay (MCOO) which is specifically designed for the preparation of the battlefield in a war scenario.<sup>55</sup>

The systems employed for IPB in terms of trafficability are similar to other methods of terrain analysis. However, it contains dimensions beyond the sphere of this chapter such as minefields and other man-made military obstacles. In terms of basic off-road trafficability IPB uses soil, vegetation, slope and hydrology which are similar to that of other negotiability models. The IPB also applies an automated trafficability model that uses configuration spaces which identify non-trafficable areas from which a topology of trafficable areas is created.<sup>56</sup>

There are some terrain negotiability models which account for soil moisture by modelling precipitation and runoff. These models use high-resolution DEMs, precipitation percentages, vegetation parameters, sky covering, solar radiation and air temperature.<sup>57</sup> Suvinen et al. developed a forest tractor negotiability model that calculates the forces of resistance on the vehicle and the terrain, as well as the influence of moisture using GIS data.<sup>58</sup> In designing a negotiability model, a holistic approach should be followed where the topography and geometry of the terrain is taken into consideration along with the rainfall and water flow.<sup>59</sup>

Besides computer-aided modelling there are also physical testing processes that can determine the relative trafficability of a land surface. Militaries generally use a specialised yet simple piece of equipment called a cone penetrometer. Cone penetrometer testing determines a soil index that is used to calculate soil trafficability and is known as the Cone Index (CI).<sup>60</sup> A cone penetrometer allows for a practical and simplistic method for determining the bearing capacity of a given soil type. The cone penetrometer test is viable during military operations or combat situations where there is sufficient time for reconnaissance.

Several models use an equation based on rating CI that calculates slow-go and no-go areas. For example, Flores et al define " $VCI1 < RCI \leq VCI 50$ " as "slow-go" and " $RCI < VCI1$ " as "no-go".<sup>61</sup> Remoulded Code Index (RCI) is calculated by taking the CI and multiplying it by the remoulded index (RI) which is determined after repetitive loads. The Vehicle Cone Index (VCI) is determined from the vehicles' specific characteristics and represents the soil strength needed to support one pass (VCI1) or 50 passes (VCI50).<sup>62</sup> The VCI for a vehicle passing over a given terrain is referred to as VCI 1 and for fifty passes over the same terrain as VCI 50.

The CI, VCI and RCI are related to trafficability and are soil-specific (coarse and fine grained soils). The critical layer is the layer of soil that supports the vehicle but does not necessarily have to be in contact with it. This is where the CI, RI and RCI are determined.<sup>63</sup>

## Modelling Terrain Negotiability in the South African Army

Military negotiability maps were extensively used in the SA Army for operations during the latter half of the 20<sup>th</sup> century. These maps took into account four factors, namely, vegetation, soils, micro and macro relief.<sup>64</sup> The creation of these maps has for the most part ceased and there is a growing need for the creation of new terrain negotiability maps for landward-based operations.<sup>65</sup> In the past, specialists were used to analyse the respective factors which influence negotiability. A botanist, pedologist and geographic surveyor would traditionally be used to examine the vegetation, soil, micro and macro relief and determine the relevant negotiability of the different terrain aspects. The terrain analyses would then be mapped by a cartographer.

There is an increased interest in re-establishing new terrain negotiability capabilities in the SA Army. There is a skills gap which, to some extent, can be attributed to the lack of transfer of technical knowledge with regard to terrain negotiability studies. In the previous system, there was a strong link between the military and academia which, in combination, provided the technical and theoretical, geographical and terrain knowledge, as well as skills to perform the required operational tasks.<sup>66</sup> The skills gap is further widened by the exponential increase and development of information technology. As a result, new engineer officers who are often competent in the use of computer-based technologies find difficulty in having to grapple with unknown, forgotten, or outdated terrain negotiability methodologies that were based on hardcopy cartographic techniques. The previous method of terrain negotiability in the SA Army involved the analysis of soil, vegetation, micro and macro relief using a quadrant system – refer to figure 6.2. To see an example of the quadrant system represented on a map refer to figure 6.4.

<b>1. Vegetation</b>	<b>2. Macro relief</b>
<b>3. Soils</b>	<b>4. Micro relief</b>

FIGURE 6.2 Descriptive legend of terrain components on a negotiability map<sup>67</sup>



In the above-mentioned model each component is allocated a value according to a variety of variables. The methodology of the system is not questioned. However, this study suggests that it is necessary to implement the terrain negotiability technique in a modern system using GIS. Each terrain component has a descriptive and an interpretative legend. The descriptive legend describes the different types of vegetation, soil and micro and macro relief, and the interpretative legend allocates a relative value to the different components and their respective typologies.<sup>68</sup>

### *Vegetation in terms of terrain negotiability*

Vegetation is important as a terrain component and can have a variety of effects on mobility. Dense vegetation, in the form of forests, can limit the movement of military forces, but the scope and type of operations must be considered. There are many aspects to consider in terms of vegetation. Types of vegetation include forests, shrublands, bushland and woodlands (refer to table 6.1). The type and density of vegetation is important when analysing a geographic area.<sup>69</sup> The descriptive legend informs the user as to the different types of vegetation present in the geographic area in question. This legend can be modified and updated as required according to current information. The interpretative legend categorises the different values in the descriptive legend and adds a negotiability value which indicates whether mechanised vehicles are able to traverse the terrain in question.<sup>70</sup>

The German advance through the Ardennes forest during the Second World War secured surprise against the Allied forces. This was an example of an over-reliance on existing natural vegetation to serve as an obstacle and which was assumed to be unpassable. Vegetation can often be modified to allow for a military force to pass, with the caveat of time and resources. The United Nations Organization Stabilisation Mission in the Democratic Republic of the Congo (MONUSCO) is currently using military engineers to build a road through a forested area occupied by the rebel group Allied Democratic Forces (ADF), in the northern part of North Kivu province and the south of Ituri. The road is being constructed from Ituri in a southwards direction and from North Kivu in a northwards direction utilising military engineers. The idea is to promote accessibility in the area, for peacekeeping and humanitarian agencies.<sup>71</sup>

TABLE 6.1 Descriptive legend of vegetation on a soil negotiability map<sup>72</sup>

CLASSES	TYPES OF VEGETATION
A0	riverine vegetation low/short/tall/high forest
B	low/short thicket, low/short bushland
B	tall/high closed shrubland
C	low/short closed woodland
D	tall/high closed woodland
E	low/short open woodland
F	tall/high open woodland
F	tall/high sparse woodland
G	low/short closed shrubland
G	tall/high open shrubland
H	low/short sparse woodland/low short open shrubland
	low/short/tall/high/sparse/shrubland, low/short/tall/high
	closed grassland, low/short/tall/high/open grassland

### *Macro relief in terms of terrain negotiability*

Relief is defined as irregularities in the landscape where macro relief refers to plains, hills and mountains among other terrain features.<sup>73</sup> Macro relief analyses calculate the percentage slope which a vehicle can negotiate. The categorisation of slope classes (refer to table 6.2) is indicated on the descriptive legend and starts at “0-2%” and goes up systematically until “30 % or more”.<sup>74</sup>

TABLE 6.2 Descriptive legend of macro relief<sup>75</sup>

CLASS	PERCENTAGE (%) SLOPE
A	0-2 %
B	2-6%
C	6-12%
D	12-30%
E	>30%

In the previous SA Army negotiability model the macro relief interpretative legend was used to compare the trafficability of each slope class as defined in the descriptive legend of the map in question. The negotiability scale for the interpretative legend would then add a value to the different macro relief aspects.<sup>76</sup>

TABLE 6.3 Descriptive legend of micro relief as it appears on a soil negotiability map<sup>79</sup>

No	FEATURE
1	Rock outcrop
2	Rock outcrop present in unit
3	Loose rocks present in unit
4	Isolated anthills areas of gilgai
5	Linear dongas or stream banks
6	Steps and holes found along rivers
7	Dunes
8	Isolated pans and drainage depressions
9	Marshes

Note: \*\*\* Marks continuous rock outcrops

### *Micro relief in regard to terrain negotiability*

Strategic and operational terrain analyses may focus on macro relief. However, tactical and lower-level terrain analyses could include macro, as well as micro relief features.<sup>77</sup> Micro relief comprises various features including rock outcrops, anthills, dunes and marshes amongst others. These micro relief components are allocated a negotiability value which is used to interpret the terrain in question.<sup>78</sup> Micro relief factors should be frequently updated as dunes, dongas and other components are influenced by rain, wind and other environmental factors. This can be done by physical reconnaissance and or other remote sensing methods.

## Soil with Reference to Terrain Negotiability

The engineer officer is responsible for the compilation of data on soils that are relevant to terrain trafficability.<sup>80</sup> During Operation Hooper [1987-1988] of the Angolan War, sandy and bushy terrain was a limiting factor in the mobility of South African Defence Force vehicles.<sup>81</sup> Another example of where sandy terrain had a restrictive effect on the mobility of military vehicles was during the hybrid African Union and United Nations Mission in Darfur (UNAMID) which ended in 2016.<sup>82</sup>

The proposed model should make use of soil data which include all the different soil types in the geographic area of interest. In South Africa these soil types include lithosols (shallow soil); well drained soils; moderately drained soils; weakly drained soils; weakly drained plastic clays; soils with E horizons; very weakly drained duplex; very weakly drained soils; organic soils and loose soils (refer to table 6.4).<sup>83</sup> The soil data can be updated as required by using relevant current information sources. It is suggested that these soils be modelled by applying the relevant data on a GIS through analysing strength, drainage, carrying capacity and other factors.<sup>84</sup> Soil maps can be used on the strategic, operational and tactical levels and should indicate the impact of soils on trafficability.<sup>85</sup>

TABLE 6.4 Descriptive legend of soil classes as it appears on an old military negotiability map. The letters of the legend indicate soil class and clay content<sup>86</sup>

Soil Classes					
	NEGLECTIBLE	0-15	15-35	35-55	55-100
Lithosols	A				
Shallow Soils	A				
Well Drained Soils		B	C	D	E
Moderately Drained Soils		F	G	H	
Weakly Drained Soils		I	J	K	L
Weakly Drained Plastic Clays				M	N
Soils with E Horizons	O				
Very Weak Drained Duplex Soils	P				

Once the soils in a given area are correctly categorised according to the descriptive legend, it should be placed on an interpretative legend whereby the allocated negotiability factor is projected on a map. The descriptive legend considers topsoil and the subsoil, as well as the wet and dry season. The South African Army Engineer Terrain Intelligence Regiment, SA Army Engineer Formation Terrain Intelligence Section, as well as the Directorate of Geospatial Information should determine the parameters of subsoil depth and soil wetness. The interpretative legend applies a negotiability variable to the descriptive components.<sup>87</sup>

## **Proposed Geographic Information Systems Terrain Negotiability Model**

Terrain models can be used for planning on the different levels of war<sup>88</sup> and are a three-dimensional representation of a geographical area.<sup>89</sup> The proposed trafficability model should at a minimum make use of the negotiability components that were previously used by the SA Army. These terrain negotiability components should be modernised by developing them on maps using a GIS model. The proposed model should incorporate an existing typology of soils, vegetation types, micro and macro relief features with an established methodology so as to determine the relative negotiability per component. The suggested terrain negotiability model is intended to be the start of the discussion and by no means the final word on the subject. Where necessary the terrain typology can be expanded as required.

The suggested model should comprise data layers that can be displayed and applied in a GIS programme so as to represent the different components which should then express their relative negotiability value. There are similar existing models that present negotiability variables. These terrain models also consider the physical properties of vehicles in determining trafficable and non-trafficable areas.<sup>90</sup>

The suggested method is, in essence, a modification and modernisation of past methods of SA Army negotiability studies. The trafficability analysis using GIS will be more accurate and precise as the area identified for analysis will be exactly represented, largely in vector format on a base map and shaded in a colour representing its trafficability value. In the past, the older maps gave a negotiability value that was ascribed to a given area which did not necessarily have clearly defined boundaries and hence did not accurately represent the area in question.

GIS analysis with reviewed and current terrain data will allow for the creation of line and polygon data that will accurately show the different areas and allocate a negotiability value to each soil type, vegetation, macro and micro features per polygon. Figure 6.5 is a USA military off-road speed negotiability map created from a GIS trafficability model.<sup>91</sup>

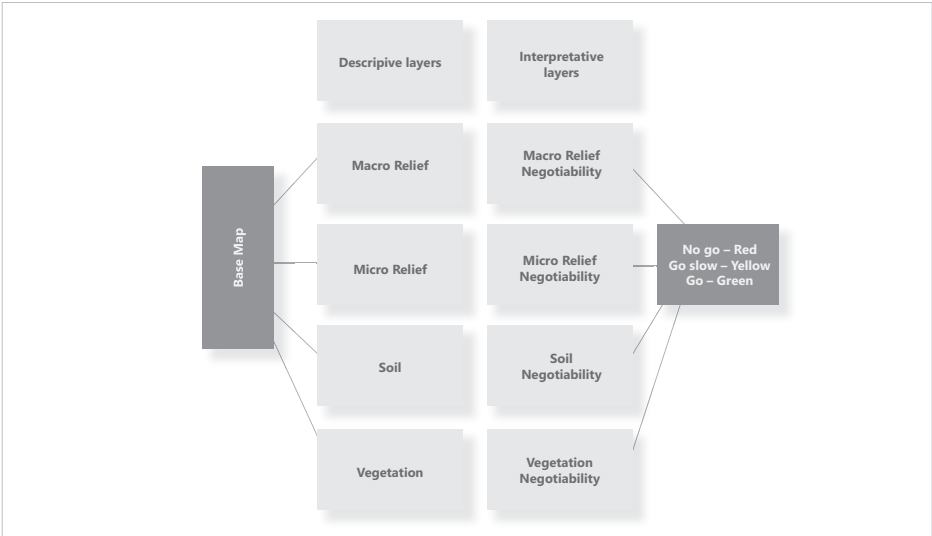


FIGURE 6.3 Terrain negotiability conceptual model

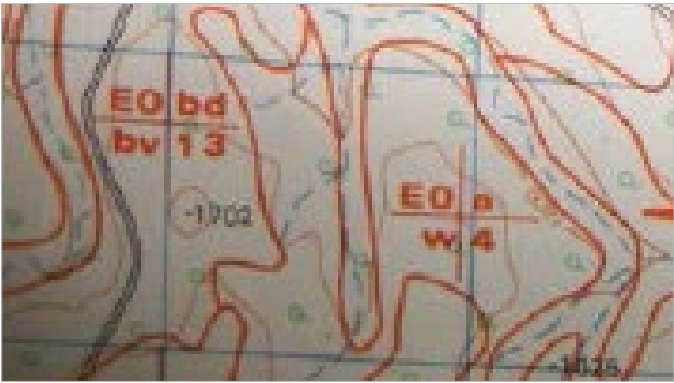


FIGURE 6.4 Terrain negotiability quadrants using the antiquated trafficability model<sup>92</sup>

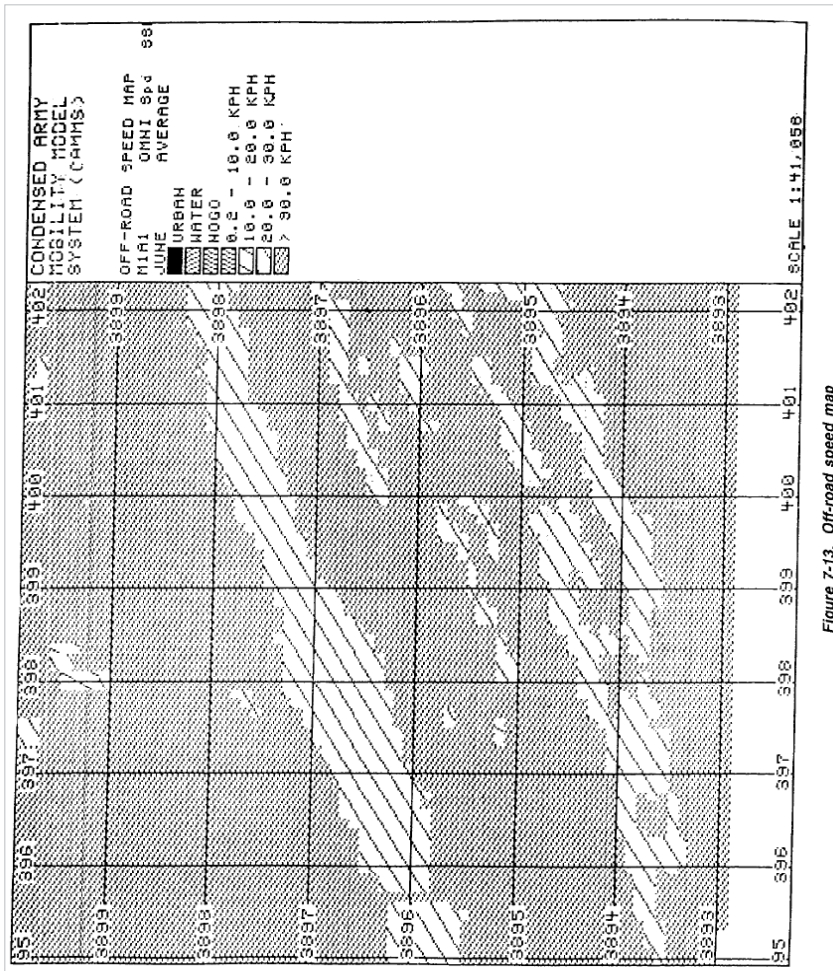


FIGURE 6.5 Off-road trafficability and speed map<sup>93</sup>

The proposed trafficability model should simplify the different negotiability values as mentioned in the interpretative legends of the antiquated trafficability model. The new model should display “green for trafficable”, “yellow for semi-trafficable” and “red for non-trafficable”. Figures 6.6 and 6.7 show terrain analyses done in North Kivu province, DRC on the Goma-Ngwenza-Nyamalima main supply route during the dry and wet seasons respectively. These maps were designed to indicate the trafficability of an axis for tactical and logistical purposes.

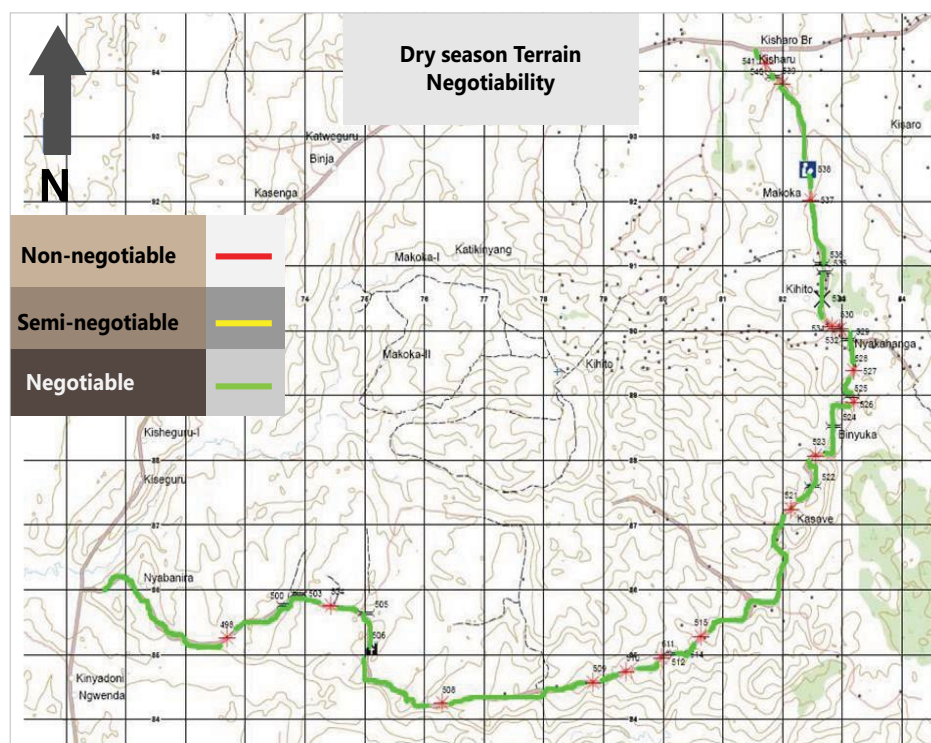


FIGURE 6.6 Terrain trafficability map for the dry season on the Ngwenda-Kihito axis as part of the Goma-Ngwenda-Nyamalima axis, North Kivu, DRC<sup>94</sup>

The terrain negotiability team should analyse the macro relief by means of a DEM – this is sometimes referred to as a slope map. The impact of the rainy season can also be calculated by determining catchment and runoff areas – this type of analysis is often discussed as part of watershed, watershed area and watershed climate analysis. The GIS should combine modern technologies to form a holistic query function which considers the various different negotiability terrain components. The modelling of the terrain negotiability components must allow for the negotiable areas to be clearly identified. The commander and staff can thus choose negotiable terrain to move their forces as required.



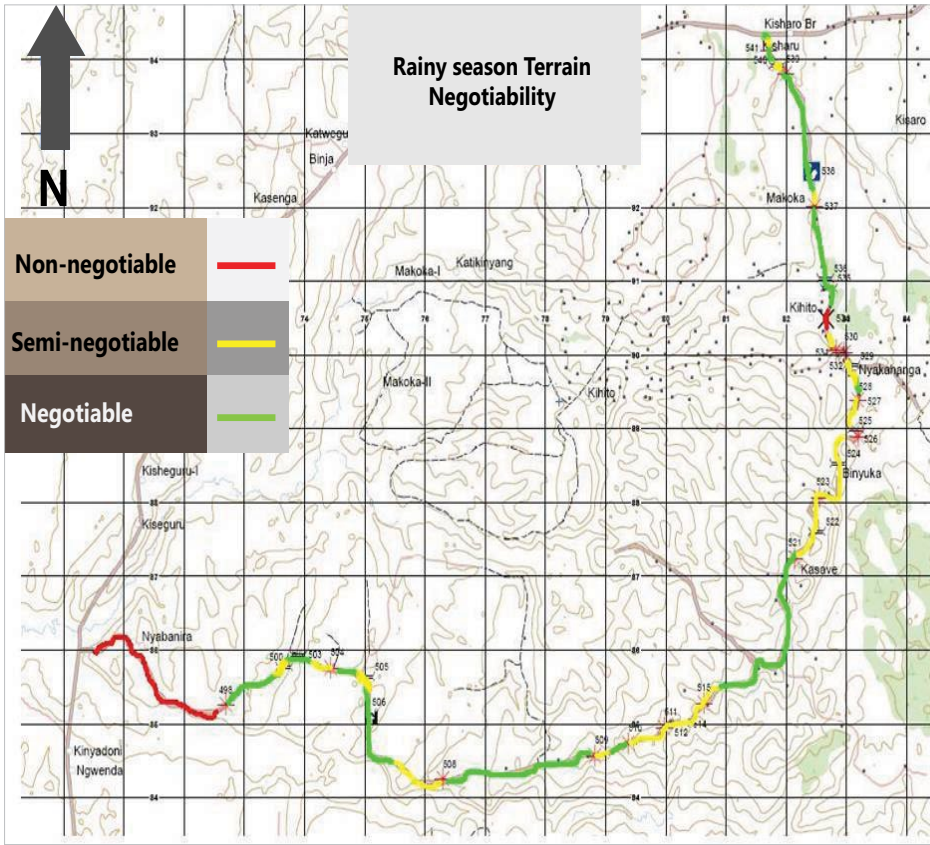


FIGURE 6.7 Terrain trafficability map for the rainy wet season on the Ngwenda-Kihito axis as part of the Goma-Ngwenda-Nyamalima axis, North Kivu, DRC<sup>95</sup>

## Conclusion

This chapter proposes a terrain negotiability model using GIS. The terrain components of the GIS model include vegetation, soil, micro and macro relief. This proposed model and application can be used by the military for land-based operations (war and/or operations other than war). The study takes a broad look at the terrain studies within the wider sphere of terrain negotiability and its application within select militaries around the world.

The ability to move military forces over off-road terrain at the right time, to the right location, with the correct supplies is of tremendous importance for military operations.<sup>96</sup> South Africa's military operations in sub-Saharan Africa, which are principally oriented towards operations other than war with a strong focus on peace missions (peacekeeping,

peace enforcement and peace building), are largely influenced by the trafficability of military vehicles. The deployment of South African military forces in sub-Saharan Africa, as part of the African Union, and/or the UN whether Chapter 6 peacekeeping or Chapter 7 peace enforcement, aims to fulfil the political objectives of South Africa in the region and continent. In order to effectively employ military forces in Africa it is essential to know where and to what extent military vehicles can operate.

During the Second World War German military geographers gathered extensive terrain intelligence on countries which they were likely to invade.<sup>97</sup> The French, British and Americans also developed extensive terrain classification and modelling systems to plan for the employment of military forces. The classification of terrain was, and is, of great importance to the military.<sup>98</sup> South Africa is not currently preparing for war. However, the principle still applies in that knowledge of the terrain in which we conduct operations other than war remain crucial to the success of military operations. The planning of military operations in the African battle space requires trafficability analyses to determine the limits of military movement on all the levels of war.

## ENDNOTES AND REFERENCES

1. For the purposes of this chapter a negotiability map indicates areas where off-road vehicle movement is unhampered, where vehicle mobility is limited and where it is completely restricted.
2. Hornback, P. 1998. The Wheel Versus Track. *Armor*, 107(2):33-34.
3. Flores, N.A.; Entekhabi D. & Bras, R.L. 2010. *Data Assimilation Approach for the Prediction of Soil Moisture at Tactical Scales Fusing Multiple Scale Data Sources and Models*. Paper presented at the 27<sup>th</sup> Army Sciences Conference, Orlando.
4. For the purposes of this chapter terrain negotiability refers to the movement of military vehicles as opposed to the movement of soldiers on foot.
5. Lodi, K.P.; Smit, H.A.P. & Ayirebi, G.K. 2014. Terrain Analysis in the Course Curricula of the South African Army Engineer Corps. *Scientia Militaria: South African Journal of Military Studies*, 42(1);  
Henrico, S.J. 2017. Analysing the practical feasibility of free and open source software for Geographic Information Systems (FOSSGIS) in Military Operations. Thesis presented in partial fulfilment of the degree Master of Arts, University of Pretoria.;  
Jacobs, A. & Smit, H.A.P. 2004. Mapping Support in the South African Military during the 20<sup>th</sup> Century. *Scientia Militaria*, 32(1).
6. USA Army. 1967. *FM 30 10: Terrain Intelligence*. Washington: Department of the Army. p.4.
7. Saarilahti, M. 2002. *Soil Interaction Model*. EU 5<sup>th</sup> Framework Project, Project delivered for Quality of Life and Management of Living Resources Contract No. QLK5-1999-00991 (1999-2002). Helsinki.

8. Lodi et al., 2014, op. cit., pp. 102-121.
9. USA Army. *FM 30 10: Terrain Intelligence*, 1967, op. cit., p. 6.
10. USA Army. 1959. *FM 5-30: Engineer Intelligence*. Washington: Department of the Army.
11. Dos Santos Cruz, C.A. 2015. Employment of Force Engineer Assets. *Interoffice Memo from MONUSCO Force Commander*.
12. Glington, R.; Giampapa, J.; Owens, S.; Sycara, K.; Grindle, C. & Lewis, M. 2004. *Integrating Context for Information Fusion: Automating Intelligence Preparation of the Battlefield*. Paper presented at the 2<sup>nd</sup> Conference for Human Performance, Situation Awareness and Automation, Daytona Beach. p. 1.
13. USA Army. 1994. *FM 5-430-00-1: Design of Roads, Airfields and Heliports in the Theatre of Operations*. Washington: Department of the Army. pp. 1-7.
14. Ibid., pp. 7-30.
15. This chapter puts forward the concept for terrain analysis using GIS, as well as the main categories of analysis. The methods of analysis should be explored in an additional study.
16. USA Army. *FM 30 10: Terrain Intelligence*, 1967, op. cit., p. 142.;  
USA Army. *FM 5-30: Engineer Intelligence*, 1959, op. cit., p. 53.
17. Gebremedhin, G. 2009. A Comparison of Expert Systems and Weighted Overlay Analysis for Military planning. Thesis presented in partial fulfilment of the degree Master of Science. University of Addis Ababa.
18. Chang, K. 2006. *Introduction to Geographic Information Systems*. New York: McGraw Hill. p. 390.
19. Van Der Waag, I. 2005. Water and Ecology in Warfare in Southern Africa. In: J.M.N. Tempelhoff (ed.), *African Water Histories: A Transdisciplinary Discourse*. North-West University: Vanderbijlpark.;  
Jacobs, J.A.; Janse van Rensburg, H.S. & Smit, H.A.P. Military Geography in South Africa at the dawn of the 21<sup>st</sup> century. *South African Geographical Journal*, 82(2);  
Smit, H.A.P. & Janse van Rensburg, H.S. 2014. Success and Failure along the Modder River during the Anglo-Boer War: The Influence of Terrain. *Scientia Militaria*, 42(4).;  
Delpont, A. 2015. *Boks and Bullets, Coffins and Crutches: An Exploration of the Body, Mind and Places of 'Springbok' South African Soldiers in the First World War*. Thesis presented in partial fulfilment of the degree Master of Arts, Stellenbosch University.;  
Kleynhans, E. 2016. A Critical Analysis of the Impact of Water on the South African Campaign in German South West Africa, 1914-1915, *Historia*, 61(2).;  
Van der Waag, I. 2015. *A Military History of Modern South Africa*. Cape Town: Jonathan Ball.  
<https://doi.org/10.17159/2309-8392/2016/v61n2a2>  
Garcia, A. 2017. A Manoeuvre Warfare Analysis of South Africa's 1914-1915 German South West African Campaign. *Scientia Militaria*, 45(1).;  
Henrico, 2017, op. cit.
20. USA Army. *FM 30 10: Terrain Intelligence*, 1967, op. cit., p. 4.
21. Whittall, W. 1917. *With Botha and Smuts in Africa*. London: Cassel and Company. p. 111.
22. Rose, E.P.K.; Hausler, H. & Willig, D. 2000. Comparisons of British and German applications of Geology in World War. In: E.P.F. Rose & C.P.Nathaniel (eds.), *Geology and Warfare: Examples of the influence of Terrain and Geologists on Military Operations*. London: Geological Society. pp. 117-118.

23. Rose E.P.K. & Willig, D. 1940. German Military Geologists and Geographers in Second World War: Roles in Planning for Operation Sealion – the Invasion of England Planned for September 1940. In: D.R. Chadwell, J. Ehlen & R.S. Harmon (eds.), *Studies in Military Geography and Geology*. p. 199.
24. O'Sullivan, P. & Miller, J.W. 1983. *The Geography of Warfare*. London: Routledge. pp. 23-25.
25. Rose, Hausler, & Willig. 2000. British and German. In: Rose & Nathaniel, *Geology*. op. cit., p. 113.
26. O'Sullivan & Miller, 1983, op. cit., pp. 23-25.
27. Jacobs & Smit, *Mapping Support*. 2004, op. cit., pp. 46-48.
28. UK Army. 2012. *Joint Concept Note, 2/121. Future Land Operating Concept*. Swindon: Ministry of Defence. p. 1-2.
29. Australian Army. 2009. *Army's Future Land Operating Concept: Adaptive Campaigning*. Canberra: Australian Army HQ. p. 9
30. UK Army. Joint Concept Note 2/121, 2012, op. cit., p. 2-2.
31. USA Army. 2014. *TRADOC Pamphlet 525-3-1: The USA Army Operating Concept, Win in a Complex World 2020-2040*. Fort Eustis: TRADOC Publications. p. 12.;  
Garcia, A. 2017. *Proposed South African Army Future Deployment Concept System: The Capstone Concept and the Operating Concept*. Winning paper for the SA Army Writing Competition.  
[Online]: <https://bit.ly/2unQjZl>
32. SA Department of Defence. 2015. *South African Defence Review 2015*. Pretoria: Government Printing Works. pp. 2-19.
33. For the purposes of this chapter the combat zone refers to operational area of the fighting echelon and the communication zone refers to area of operations of the A and B echelons.
34. USA Army. *FM 30 10: Terrain Intelligence*, 1967, op. cit., p. 27.
35. MONUSCO Engineer Section. 2015. Planning of Major and Minor Projects and Tasks. *Integrated Military Engineer Conference*.
36. USA Army. *FM 30 10: Terrain Intelligence*, 1967, op. cit.;  
USA Army. *FM 5-430-00-1: Design of Roads*, 1994, op. cit.
37. USA Army. *FM 5-430-00-1: Design of Roads*, 1994, op. cit., pp. 7-12.
38. Chang, 2006, op. cit., p. 391.
39. Heywood, I.; Cornelius, S. & Carver, S. 2011. *Introduction to Geographic Information Systems*. New York: Pearson Prentice Hall. p. 18.
40. Chang, 2006, op. cit., p. 1.
41. USA Army Corps of Engineers. 2000. *Manual 1110-2-1913: Design and Construction of Levees*. Washington: Department of the Army. p. 2.
42. USA Army. *FM 30 10: Terrain Intelligence*, 1967, op. cit., p. 142.
43. Corripio, J.G. 2003. Vectorial Algebra Algorithms for Calculating Terrain Parameters from DEMs and Solar Radiation Modelling in Mountainous Terrain. *International Journal of Geographical Information Science*. 17(1):1-23. <https://doi.org/10.1080/713811744>
44. Suvinen, A.; Tokola, T. & Saarilahti, M. 2009. Terrain Trafficability Prediction with GIS Analysis. *Forest Science*, 55(5):433-442.;  
USA Army. *FM 30 10: Terrain Intelligence*, 1967, op. cit., p. 142.

45. Blundell, S.B.; Guthrie, V. & Simental, E. 2004. Terrain Gap Identification and Analysis for Assured Mobility. Paper presented at U.S. Army Topographic Engineering Research and Development Center, Alexandria.
46. Heywood, Cornelius & Carver, 2011, op. cit., p. 222.
47. USA Army. *FM 30 10: Terrain Intelligence*, 1967, op. cit., p. 13.
48. Ibid., p. 5.
49. Virrantaus, K. 2003. Analysis of the Uncertainty and Imprecision of the Source Data Sets for a Military Terrain Analysis Application. Research report presented at Helsinki University of Technology. p. 1.
50. Richmond, P.W.; Scoggins, K.; Yamauchi, H. & Gates, B.Q. 2007. Common Ground Vehicle Route Planning for Army Simulations. Paper 07S-SIW-062 presented at the Simulation Interoperability Workshop. Norfolk.
51. Ibid., p. 2.
52. Yang, Y.K.; Jeong, I.S.; Lee, J.H.; Kim, K.O.; Choi, K.H. & Seo, D.J. 1994. Development of an Interactive GIS Technique for Simulating Intelligence Preparation of the Battlefield. In Urban and Region Information Systems Association. *GIS/LIS.Proceedings*. Phoenix: American Society for Photogrammetry & Remote Sensing. pp. 843-850.
53. Suvinen, A. 2004. An Off-Road Routing using GIS Analysis. *Scientific Herald* 14(3):389-397.
54. Suvinen, A.; Saarilahti, M. & Tokola, T. 2003. Terrain Mobility Model and Determination of Optimal Off-Road Routes. Paper presented at the 9th Scandinavian Research Conference on Geographical Information Science. Espoo, p. 28.
55. Glington, 2004, op. cit., p. 2.
56. Ibid., p. 3.
57. Flores, Entekhabi, Bras, 2010, op. cit., p. 3.
58. Suvinen, Tokola & Saarilahti, 2009, op. cit., p. 433.
59. Gessler, P.E.; Moore, I.D.; McKenzie, N.J. & Ryan P.J. 1995. Soil-landscape Modelling and Spatial Prediction of Soil Attributes. *International Journal of Geographical Information Systems*, 9(4):421-432.;  
Further GIS analysis which is related to rainfall pertains to flood modelling and planning.;  
Henrico. 2017, op. cit., pp. 5, 27.
60. Shoop, S.A. 1993. *CRREL Report 93-6: Terrain Characterization for Trafficability*. Project delivered to USA Army Corps of Engineers Research and Development Center Cold Regions Research and Engineering Laboratory (DA Project 4A762784AT42). Hanover, p. 2.
61. Flores, Entekhabi, Bras, 2017, op. cit., p. 4.
62. Ibid., p. 9.
63. USA Army. *FM 5-430-00-1: Design of Roads*, 1994, op. cit., p. 1-7.
64. Map 2531AB Pretoriuskop Grid Zone 36J, 1971.
65. Interview with military terrain intelligence officer, 2016.
66. Jacobs & Smit, *Mapping Support*, 2004, op. cit., p. 47.
67. Map 2531AB Pretoriuskop Grid Zone 36J, 1971.

68. Ibid.
69. USA Army. *FM 30 10: Terrain Intelligence*, 1967, op. cit., p. 136
70. Map 2531AB, 1971, op. cit.
71. Interview with Mission Support officer, MONUSCO.
72. Map 2531AB, 1971, op. cit.
73. USA Army. *FM 30 10: Terrain Intelligence*, 1967, op. cit., p. 44.
74. Map 2531AB, 1971, op. cit.
75. Ibid.
76. Ibid.  
Macro relief is also important in terms of flood modelling and planning as well as understanding catchment areas.
77. USA Army. *FM 30 10: Terrain Intelligence*, 1967, op. cit., p. 136.
78. Map 2531AB, 1971, op. cit.
79. Ibid.
80. USA Army. *FM 5-30: Engineer Intelligence*, 1959, op. cit., p. 53.
81. Oosthuizen, G.J.J. 2014. The South African Defence Force and Operation Hooper, South East Angola, December 1987 to March 1988. *Scientia Militaria*, 42(2):106.  
<https://doi.org/10.5787/42-2-1095>
82. Interview with SA Army senior officer in UNAMID.
83. Map 2531AB, 1971, op. cit.
84. This chapter puts forward the categorisation of elements to be modelled using a GIS for negotiability analysis. However, the 'how' requires further research using the latest information technology.
85. USA Army. *FM 30 10: Terrain Intelligence*, 1967, op. cit., p. 9.
86. Map 2531AB, 1971, op. cit.
87. Ibid.
88. For the purposes of this chapter, Strategic, Operational and Tactical.
89. USA Army. *FM 30 10: Terrain Intelligence*, 1967, op. cit., pp. 81-83.
90. USA Army. *FM 5-430-00-1: Design of Roads*, 1994, op. cit., p. 7-30.
91. Map 2531AB, op. cit.
92. US Army. *FM 5-430-00-1: Design of Roads*, 1994, op. cit., p. 7-31.
93. Ibid.
94. Staff Officer for Military Engineers North Kivu Brigade MONUSCO. 2015. *Terrain Study of the Ngwenda – Kihito Axis as part of the Goma – Ngwenda – Nyamalima Axis*. Terrain Study. Goma.
95. Ibid.
96. Flores, Entekhabi, Bras, 2017, op. cit., p. 1
97. Rose & Willig, 2000, op. cit., p. 210.
98. Saarilahti, 2002, op. cit., p. 1.

# South African Army Mobility Modelling Software and its Future Challenges



David Reinecke, Phumlane Nkosi & Rayeesa Ahmed



## Introduction

The SANDF software suite, Mobility Simulations (MOBSIM), was developed out of a range of vehicle research projects executed primarily at the University of Pretoria Laboratory for Advanced Engineering (LGI) with inputs from University of Potchefstroom, Reumech and Land Mobility Technologies (LMT) Engineering.<sup>1</sup> Although leading edge when it was developed in 2006, the MOBSIM software suite requires updating and improvement to harness increased computational modelling power, new computational models available, as well as remote sensing and in-situ data obtainable today.

MOBSIM off-road mobility modelling is based on the Bekker-Wong and Janosi-Hanamoto tractive effort model that makes use of soil shear and penetration data obtained using a Bevameter<sup>2</sup> to generate parameters for pressure-sinkage and shear stress-displacement relationships for soils of interest. This methodology is deemed a simple terramechanics



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model<sup>3</sup> and despite considerable research effort in the 1990s, appears to not have been implemented in other common military mobility modelling software.<sup>4</sup> Why this method has not been widely applied within military modelling software is not known. It is surmised that it is in part due to difficulties with the Bevameter that by definition has to be large and is thus difficult to deploy in remote areas and variability of the results generated across apparently homogenous terrain. The current NATO vehicle mobility modelling software relies on the CI and is also deemed a simple terramechanics modelling technique.<sup>5</sup>

Based on recent international military experiences leading to various military research imperatives<sup>6</sup> and military vehicle acquisition programs, there has been renewed interest in terramechanics and mobility modelling methods leading to initiatives to improve computational modelling of military vehicle mobility. These range from verifying and validating the Bekker-Wong models to the development of physics-based terramechanics models using Discrete Element Modelling.

This resurgent military vehicle mobility modelling research has led to the review of existing soil parametrisation techniques and classifications with the purpose to identify and develop enhanced or new methods and techniques for vehicle mobility modelling in relevant, applicable and realistic terrains. This work includes enabling accurate soil model Equations of State (EOS) to be parametrised and validated. This growing body of knowledge serendipitously provides material support for the updating of the SANDF mobility software MOBSIM.

This chapter will introduce the SANDF mobility modelling suite MOBSIM, highlighting where geoscience outputs are currently used to model off-road vehicle mobility. This is followed by the introduction of the Discrete Element Modelling approach being developed for enhanced military vehicle mobility modelling and the geo-parameters that are required for this work. The gaps in the geoscience data and models required for these mobility simulations, as well as how these are planned to be obtained and the challenges being faced are presented to encourage the greater geosciences community to assist in the generation of these required models and data.

The purpose of this article is to make the South African developed MOBSIM software suite visible to SANDF personnel involved with equipment acquisition, operations planning and engineering support. It is hoped through this awareness to raise sufficient interest within the SANDF and Armscor that personnel will obtain and use MOBSIM and thus assist with the updating, upgrading and improvement of the software suite to meet future SANDF needs.



## SANDEF Mobility Software

MOBSIM was purposefully developed to naturally lead the user through the standard vehicle development process. This software suite consists of six separate modules, each building up data that is used to evaluate the proposed or existing system. These modules are, in order of use, Mean Maximum Pressure Simulation (MMPSim), Vehicle Simulation 2D (VehSim2D), Ride Comfort (RideCom), Visual Basic Drive (VBDrive), Genrit [three-dimensional (3D) multi-body dynamics modelling] and South African Army Mobility Model (SAAMM). An additional module called VBElectric Drive has been developed and verified, but is not yet integrated into MOBSIM. This module, as its name suggests, is used to support the design and modelling of electric drive vehicles.

### *Mean Maximum Pressure Simulation*

The first step in vehicle design is to determine the number of axles, wheel size or number of wheel stations and track width for tracked vehicles, based on the target design mass of the vehicle that will ensure mobility within the planned operational environment. MMPSim uses three semi-empirical methods of which two are Mean Maximum Pressure (MMP) implementations as developed by Rowland and then modified by Larminie and the third is the Vehicle Limiting Cone Index (VLCI).<sup>7</sup> These three methods enable the user to confirm basic vehicle trafficability in terms of go/no-go for a terrain through the MMP or VLCI using vehicle mass, number and operation mode of axles, tyre deflection and tyre size. The MMP and VLCI are related to trafficability by using the CI of the soil. For MMP a factor of 0,825 is used to relate CI to MMP as proposed by Rowland.<sup>8</sup> The number of passes the vehicle configuration can achieve can be estimated using the MMP calculated CI and a table of CI modifier values ranging from one up to fifty passes. Using VLCI and MMP the user or designer is able to gauge the indicative performance of the selected vehicle design and then change mass, number of axles and mode, as well as tyre geometry and size until a suitable ground pressure is achieved for the required vehicle trafficability in soft soils.

### *Vehicle Simulation 2D*

The next vehicle design or evaluation step is the suspension. This is executed using VehSim2D which implements a two-dimension (bicycle) vehicle model that enables the suspension system to be designed, evaluated and optimised using suspension and tyre geometry with related parameters such as stiffness and damping. The software provides the option of a Sector Tyre or a Point Follower method for calculating the suspension response. Other model inputs required are vehicle mass (sprung and unsprung), centre

of gravity, vehicle speed, route profile, etc. This software has the Leap-Frog Algorithm for Constrained Optimisation (LFOPC)<sup>9</sup> programmed in to enable the suspension to be optimised for specific scenarios by the user. Thus, the vehicle suspension design can be evaluated for a range of speeds over a test track, route or specific obstacle. The surface input requires a user defined input which is typical test track profiles such as a v-ditch, half-rounds, step-climb, washboards or Belgian paving. The model outputs displacement, velocity and acceleration at the Centre of Gravity (CoG), the front and rear occupant seat bases for the specific vehicle speed, road surface or obstacle for each suspension design.

The program has simple graphics that enable vehicle geometry effects to be visualised such as ability to do ditch crossing, etc. The vehicle suspension design can be evaluated based on the model results and then changed or optimised. VehSim2D enables suspension designs to be quickly assessed and compared, as well as determine the effect of operational issues on suspension performance, such as lower tyre pressure, obstacles, etc. VehSim2D calculates Root Mean Square (RMS) and Vibration Dosage Value (VDV), but does not calculate ride comfort. VehSim2D provides the required formatted output acceleration for the CoG, front and rear occupants that are used by the RideCom program to calculate the ride comfort.

### *Ride Comfort*

Ride comfort is probably the limiting off-road performance factor for a vehicle, affecting not only the occupants, but also the cargo.<sup>10</sup> Occupants can suffer external and internal injuries, motion sickness and fatigue<sup>11</sup> based on the vehicle response to the surface traversed. The human body responds differently to different frequencies with the physiological effects dominating in the 1-20 Hertz range.<sup>12</sup> Various ride comfort standards have been developed over the years and RideCom can process both simulated (VehSim2D and Genrit) and actual measured data to calculate the ride comfort levels in accordance with the following four standards: 1997 ISO 2631, BS 6841, the 1987 German VDI 2057 and Averaged Absorbed Power.<sup>13</sup>

VehSim2D does not include the ability to model seat transmissibility. RideCom thus provides the ability to add a seat transmissibility function measured using a locally developed methodology<sup>14</sup> to the model or measured vibration data. This enables the effect of the seat on the calculated ride comfort to be assessed. A library of five seats is included with the software and other seats can be added as required. By interactively working with VehSim2D and RideCom, initial suspension design trade-offs based on ride comfort can be explored by the user. 3D Genrit Multi Body Dynamic's (MBD) simulation

results, discussed later, can also be input into RideCom and the modelled design or system evaluated in terms of ride-comfort for various suspension and tyre settings, terrains and/or obstacles including asymmetric terrain effects.

### *Visual Basic Drive*

The next step in the vehicle design process is defining and balancing the power train and performance modelling of expected performance. The process is defined by the VBDrive module. Although the user could skip this module and go straight to the three-dimensional modelling in Genrit, defining the power train and determining the expected performance over various terrains and/or routes will provide the user with a realistically achievable range of Genrit model input parameters such as maximum speed, maximum slope, etc. The key output of VBDrive is the net tractive effort and derived vehicle performance for both on and off-road terrains for the specific combination of selected driveline components for the vehicle system. There are two VBDrive modules, one for internal combustion engine driven vehicles and another for electric drive vehicles. Although the simulated performance outputs are the same some of the power train components differ. This chapter focuses on the combustion engine VBDrive module.

Using the generated tractive effort, VBDrive calculates a range of key vehicle mobility performance parameters, such as maximum and minimum geared speeds on different gradients, and surfaces and maximum gradient capabilities of each gear. VBDrive simulates acceleration from standstill and the time required to attain different vehicle speeds, the overtaking acceleration times and distances for specific gears and the fuel consumption of the vehicle at a range of selected constant speeds and gears. VBDrive simulates the performance of the vehicle over a user-prescribed route profile. The route simulation uses a simple driver model whereby the maximum achievable speed is obtained based on net tractive effort, slope, wind resistance and acceleration performance. The user can input limitations on any of these parameters to modify the simulation. The route results can be used to estimate the range of the vehicle, the average fuel consumption, average speed, etc. that can be achieved. VBDrive also calculates the optimum up and down gear shift points for best acceleration for Wide Open Throttle (WOT) to enable the initially selected gear shift points to be reviewed and, if required, updated. This is of particular use if an unstable simulation result is achieved, such as continuous up-down shifting. VBDrive simulates braking performance of the vehicle for a user-selected range of speeds providing deceleration, distances and times at outputs. The simulation cannot model Antilock Braking Systems (ABS) directly and works on a simple user-defined braking efficiency allocated to the front and rear wheels. ABS

performance can be estimated by allocating high percentage efficiency. Using initially calculated net tractive effort over a range of selected gradients VBDrive simulates the vehicle hill climb performance up a user-specified incrementally increasing gradient.

The simulated and calculated outputs are provided in a range of plots and tabulated numerical data for each simulation. VBDrive enables comparison between two vehicles of the same kind, but with different drive train configurations to be compared in terms of simulated performance outputs.

To derive the required performance outputs, the model is developed first as a series of drive train components and then combined with a defined set of general vehicle parameters. The drive train model input is separated into twelve generic components. These are: engine, connecting gearbox, accessories, clutch, torque convertor, transmission, transfer gearbox, final drive, wheel or track and steering gearbox. These typical drive line components and inputs for each were based on vehicle technology available in 2004. The engine data input required is divided into four sections covering general information, full load characteristics, partial load characteristics and engine operating characteristics. General information covers aspects such as ignition type, aspiration, engine braking, etc. Full load engine data requires engine output and absorbed power and torque for varying engine speeds. Ambient conditions effects are taken into account by noting the ambient temperature and altitude at which the engine performance was obtained. Engine part load data requires fuel consumption data for various engine speeds and power output levels or it can estimate fuel consumption. The last input data requires information such as inertia, response time, minimum and maximum engine speeds.

The connecting gearbox, transmission, transfer gearbox, final drive and steering gearbox all have similar input requirements needing ratio, efficiency and inertia of each. The transmission requires additional data such as spin loss for each forward and reverse gear while the transfer gearbox can allow up to two reduction stages and the final drive allows for both the differential and wheel hub reduction ratios. The clutch requires both input and output inertia and coupling time along with maximum transmitted torque. The torque converter input requires information such as the torque ratio and capacity factors for various engine speeds and lock-up/unlock schedule. Three lock-up/unlock control modes are offered as standard. To assist the designer or procurement office regarding the selection and matching of the engine, torque convertor and connecting gearbox, the torque convertor module allows for performance plots to be generated where performance of the components can be assessed. This functionality takes the accessories driven off the engine into account.

Accessories can, and do, place a large power burden on the vehicle power train. Thus, the user is prompted to include primary accessories such as the cooling fan, alternator, power steering and air-conditioning by specifying each item's speed ratio, inertia and efficiency along with the speed, power and torque maps. The program allows for direct drive, as well as power take-off transmissions to be used for the accessories. The user can define additional accessories. As with the other power train items the efficiency, inertia and power/speed maps are required.

For the tracks and wheels, the required modelling data is divided into three input sets. For tyres, these are general data, rolling resistance and tractive force data. The *general tyre data* requires carcass stiffness, rolling radius, unladen tyre diameter, width, inertia, maximum speed and maximum slip for the simulation. For *rolling resistance*, the coefficient matrix for the tyre in terms of wheel speed and vertical loads is required. The required rolling resistance coefficient matrices for hard surfaces, such as asphalt or gravel for either cross or radial ply tyres and deformable soils can be input from measured data if available or estimated using pre-programmed data. The third data set is the *tractive effort coefficient* curves (matrices) for the tyres on hard surfaces and deformable soils. For paved or hard surfaces, these curves can be manually input from measured data or estimated using pre-programmed data for a range of tyre types on asphalt or a hard soil surface. For deformable soil, rolling resistance and tractive effort are automatically calculated using six Bekker-Wong and Janosi-Hanamoto parameters derived from Bevameter tests.<sup>15</sup> These parameters are: the cohesive modulus, frictional modulus and exponent of deformation derived from Bevameter penetration tests and cohesion, internal angle of friction and horizontal shear modulus of deformation derived from the Bevameter shear plate tests.<sup>16</sup> For tracks, the three input data sets required are track geometry, rolling resistance and tractive effort coefficient matrices.

The general track data required are the sprocket radius, front road wheel diameter, track and grouser geometry, mechanical loss coefficients, inertia, etc. As with tyres (wheel), the track rolling resistance and tractive effort versus load and slip coefficient matrices can be input manually from test data or estimated using pre-programmed values. Similarly for soft soil, the six Bekker-Wong and Janosi-Hanamoto<sup>17</sup> parameters are used to calculate the track rolling resistance and tractive effort coefficient matrices.

Once the model *component database* is completed, the *vehicle database* must be compiled for each vehicle to be modelled. The vehicle database input data consists of three data sets which are: general vehicle characteristics, component file names and lambda factors (inertia effects) and maximum engine speed in gears. The *general vehicle*

*characteristics* information defines the general power train configuration of the model to assist in ensuring all relevant components are linked. These include selections for tracked or wheeled vehicle, types of gearboxes used and whether accessories are fitted. Additional numerical data such as frontal drag area (CdA), number of axles, wheel base dimensions, axle loads, drive torque distribution, brake efficiency and centre of gravity height are required. The user can also specify the environmental conditions in terms of ambient pressure and temperature, as well as wind speed. The *component file name* data requires the user to link the relevant component's files from the developed model component database. The program listed vehicle component files are determined by the selections made as part of the general characteristics – thus, only relevant components are required to be linked. The last data required before simulating the vehicle model is *lambda factors (inertia effects) and maximum engine speed in gears*. The lambda factor refers to transmission rotational inertias that are required for transient simulations. VBDrive uses an equivalent mass approach to rotational inertia effects modelling.<sup>18</sup> This approach is to enable the designer to either use the individual component drive line inertias, if known, to calculate the lambda factor or to use a semi-empirical formula to estimate the lambda factor for each gear.

Once the vehicle model (database) has been completed the performance can be simulated. The *simulation* module guides the user through the range of simulations available, starting with tractive effort and ending with the hill-climb. Options provide for forward and reverse modes, as well as high or low range. Once the primary vehicle simulation has been completed, additional performance simulations can be run for acceleration, overtaking acceleration, fuel consumption, route, brake and hill climb. The simulation results can be output to a standard summary report format and exported for use in the SAAMM module.

### *Genrit (3D multi-body dynamics modelling)*

Once the vehicle drive train performance has been determined and modelled in VBDrive, the three-dimensional rigid MBD analysis of the vehicle can be executed using the Genrit module. Note that the three-dimensional analysis can be implemented before or after the two-dimensional bicycle and power train models have been completed. However, the design methodology of MOBSIM is to ensure that initial suspension design changes and optimisation is completed on a simpler model and that the expected performance of the vehicle system is known. This information is used to set the bounds of performance manoeuvre for which to assess the design. Genrit is able to model both wheeled and tracked vehicles. Genrit is a Fortran 77 based program initially developed

by the University of Pretoria for Armscor over a number of years starting in the 1980s with the last upgrade completed in 2004. Very limited changes were made to Genrit in 2004 as it was assumed that commercially available packages would be used that were not available previously due to sanctions. This decision did not take into account the high cost of such software, as well as the licencing implications.

Genrit allows the kinematics of the vehicle system to be modelled as a series of rigid bodies (components) and force elements constrained through joints. Genrit is structured to lead the user through various menu options to build, verify and simulate the model. As this is a lumped mass representation of the vehicle rather than the full vehicle, the model consists of components that are geometrically input in terms of their centre of mass, mass and moments of inertia within a global coordinate system. If an element's location cannot be geometrically specified in terms of its centre of gravity, then the user must also include the relevant products of inertia for the part. The *constraints* are then specified and as with most MBD software packages include *spherical* and *revolute joints*, *connecting rods* and *general constraints* which are limited to single degree of freedom for each. The specification of *force elements* is required next. Genrit includes linear, torsional, combined linear (leaf springs) and combined torsional (anti-roll bars) force and includes elements. The force element characteristics are input in two (single dependency) or three dimensional (two dependencies) tabulated data called *functions*. For example, dampers which have both displacement and velocity dependencies can be modelled. The user can include custom force elements through scripting of subroutines. External forces must be defined. Genrit uses *wheels and external forces* to input these data. As external forces are generally applied through the wheels these are grouped here. Other external forces, such as cannon recoil and cross winds, can be defined through scripting if applicable.

The next step is the specification of the tyres, wheel, steering and driving models. This module requires the quantity of axles and of tyres per axle, the type of tyres and if the axle is steering or non-steering, to be specified. In addition, the tyre model data is required in specific numerical values such as unladen tyre radius or in tabulated functions such as stiffness, damping, accelerative and braking tractive effort coefficients, etc. For side forces a Pacejka tyre model is used. The software has Ackerman<sup>19</sup> steering as a standard option. The software includes five other steering options that accommodate different steering ratios between right and left tyres on an axle, steering ratio as a function of speed and/or steering tempo, etc. Genrit requires the steering axle kingpin and rotation axle distances and a steering function containing tabulated data of the camber angle versus steering angle. The driving and braking force ratio applicable for each axle must

be specified along with the displacement and velocity points of interest (POI) that are to be used by the driving model. The last input required for the tyres, wheel, steering and driving models is the terrain, driving and steering model.

The steering model includes driver reaction time. Symmetric or asymmetric terrain profiles can be used and are specified in a tabular format function for each side of the vehicle. In addition to providing terrain data, the user needs to define the test that the vehicle is to execute. Only a Sector tyre<sup>20</sup> model is available in Genrit. There are four driver steering models available of which two require tabulated data functions. These are: fixed steering angle, follow prescribed route, prescribed steering angle versus time and prescribed steering angle versus distance. These steering models are based on the steering angle of the front right hand side wheel and thus do not model the steering mechanism. The driving model refers to the power train output and is modelled from the transfer gearbox input. Genrit does not model the power train performance. For the driving model there are nine options of which eight require tabulated data functions to be defined. These are, for example, constant prescribed driving torque or speed or prescribed speed versus time or distance, etc. The time, distance or speed based torque functions can be derived using VBDrive.

The Genrit program can be set up to support a range of typical vehicle performance and evaluation tests such as symmetric and asymmetric wash-board, half-rounds, constant radius turns, step climb, ditch crossing and double lane change. Genrit outputs only plot data for selected points of interest defined on the model. Genrit provides a simple wire graphic representation simulation of the vehicle. Although simple, it provides sufficient visual data to enable the user to analyse the vehicle response or performance and make required design changes during the initial design process or evaluate and compare existing vehicle contenders for an acquisition project. The terrain data functions used for Genrit models can be real world physically measured data using contact methods such as the Armscor profilometer or non-contact methods such as LiDAR or direct laser scanners or it can be virtual terrain or obstacles. The software user can thus define their own type of terrain or obstacles or combinations thereof as required. These terrain or obstacle profiles can also be used with VehSIM2D.



## South African Army Mobility Model

The last MOBSIM module discussed in this chapter is SAAMM. SAAMM uses the various vehicle model outputs generated by RideCom, VehSim2D, VBDrive and Genrit to generate vehicle performance maps on any defined terrain and to visualise these results within a GIS. SAAMM uses ArcGIS® 9.0 as the GIS platform.

Typically, the user will initially work with ArcMAP® to identify the area of interest where vehicular performance prediction is required. Using ArcGIS®, the required terrain datasets for the identified analysis area are extracted from the GIS software database. These data are typically soil type with related mobility parameters and slope, as well as prescribed routes. Most of these soil and terrain data is used as input for VBDrive, VehSim2D or Genrit to calculate the net tractive effort, ride comfort and obstacle performance of the vehicle for each soil and terrain type. These calculated data are then transferred back to SAAMM and added as additional data layers (traction and roughness coefficients and a terrain index). Further terrain data required from ArcGIS® for SAAMM to calculate outputs are vegetation cover, height, leaves and stem sizes, as well as macro-relief. The surface roughness coefficient is required for each terrain unit. This can be either measured or calculated.

SAAMM is launched from ArcVIEW® and links the vehicle model performance output files to the selected mobility analyses to be executed for each terrain unit. To accommodate natural terrain variability SAAMM allows the user to select deterministic or stochastic mobility analyses. For stochastic analyses, any number of runs can be executed as selected by the user. This stochastic functionality was introduced to enable critical vehicle mobility-limiting environmental (terrain) factors that vary naturally or are weather dependant to be modelled and to assess the effect of these variances on the vehicle's predicted performance. These factors are roughness and traction coefficients, rolling resistance and vegetation cover (spacing), height, stem thickness and leaf size. The traction coefficient and the rolling resistance address soil strength effects and are derived from Bevameter or test data. The stochastic model is limited to a user-selectable normal or random distributions and percentage variability for each of the seven identified terrain factors. The driver eye height must be specified and can also be stochastically modelled to accommodate ergonomic changeability of the operators. This height is used for the driving visibility model.

SAAMM also allows the user to select complete-area (global) or a mission-specific analysis to be executed for the selected vehicle system. The mission-specific analyses only investigate the vehicle performance over the selected mission path terrain units

and thus are executed quickly. For the global analysis, the vehicle performance for every terrain unit in the selected ArcMAP® area is computed. As each ArcMAP® terrain unit within the selected area comprises a 20 x 20 metre area, this analysis takes much longer. Another aspect is that ArcGIS® slopes do not have cardinal direction and as such the vehicle performance can be user selected to be calculated in one direction or in eight directions to cover all possible straight-line traverses across the terrain unit.

The SAAMM module calculates the vehicle's predicted vehicle performance in terms of maximum average speed for every terrain unit in the selected analysis area. The calculation uses the maximum vehicle tractive effort available based on the soil parameters and slope within the terrain unit. From this available vehicle tractive effort, the rolling resistance, vegetation resistance, as well as air resistance are deducted. The resultant net tractive effort is used to calculate the maximum average speed that could be achieved by the vehicle in that terrain unit. The tractive effort is calculated using the terramechanics parameters and the VBDrive module. These parameters are based on actual soil measurements. To take soil moisture into account, additional measurements are required to generate the corresponding resultant soil traction parameters.

Although the vehicle could achieve the theoretical maximum average speed within the terrain unit, as determined by the available net tractive effort, other aspects such as visibility, terrain roughness and external motion resistance serve to reduce the maximum speed achievable. SAAMM has a simple driver model based on driver visibility using ergonomic eye height, terrain elevation and vegetation density. The vegetation density includes user specified leaf coverage percentage and size, as well as stem size for the terrain unit being analysed and the surrounding terrain units. The driver model uses these environmental data in combination with the braking performance of the vehicle on that specific terrain unit soil to limit the maximum average speed obtainable. In addition to the visibility restrictions, the vegetation stem size and distribution density affect mobility through external motion resistance by requiring tractive effort to push through, reducing the net available tractive effort available for speed. If net tractive effort is insufficient to push through the vegetation a no-go condition is created. The user has the driver model option to select vegetation avoidance (drive round) which then adds distance to the traverse. The last speed restriction applied is the terrain roughness. This is taken into account in terms of calculated speed-based ride comfort that will limit the maximum speed that can be obtained within the terrain unit.

The analyses are presented either as plots and tables or as map sets within ArcMAP®. For global analyses the plots present the data as maximum speed and trafficability percentage of the terrain covered by the analyses whereas for mission-specific analyses present the average speed over distance plots, fuel consumption, as well as various terrain parameters that were encountered by the vehicle in the model. Using the ArcVIEW® functionality, various map sets can be generated for calculated mobility in addition to maximum speed. These are: driver visibility, terrain roughness, tractive-effort, etc. SAAMM enables different vehicles' performance to be compared over the same virtual or scanned terrain and the effects of environmental factors such as weather, vegetation, etc. on the vehicle system to be assessed. The user can also define specific vehicle routes or traverses as required. SAAMM currently does not have a route planning capability.

Having both graphical, as well as numerical outputs supports the envisioned range of users ranging from military planning officers, scientists and engineers through to acquisition project managers, to draw usable data sets to advise decisions in an easy-to-understand format. The program runs off a laptop, making it field deployable. To achieve the ease of use, the variability of the terrain data as contained in ArcGIS® must preferably be pre-processed and grouped, otherwise the solving time would be much longer than the current hour required to assess an area the size of around fifty thousand hectares. This consolidation is done by grouping similar terrain types based on soil type, micro-relief, etc. using SANDF methods. This evaluation and combination of similar terrain types is not trivial, can greatly affect the results achieved and requires expert geospatial technicians to execute.

The verification and validation of MOBSIM, including SAAMM, was completed in the early 2000s using SANDF combat and logistic vehicles traversing the South African Combat Training Centre (SACTC).

## **Mobility Simulations Limitations**

Although MOBSIM as a single software package was ahead of its time when developed and validated, computational hardware and software capabilities have increased exponentially as has understanding and modelling of vehicle mobility. The software platforms within which MOBSIM were developed has been updated, making it difficult to run the current software suite fully. Specific modules requiring attention are Ridecom, Genrit and SAAMM.

Vehicle technology has advanced and new standard components such as double disc clutches are not available options in VBDrive. Although theoretically possible to model vehicle control systems such as ABS and semi or fully active suspensions in Genrit, the inability to compile the required Fortran 95 subroutines (scripts) within the current Windows operating environment makes this difficult.

The graphics available with Genrit are limited and lag far behind what is currently available on other software packages. Linked to this, the standard pre-programmed set of multibody models are limited, in particular a simple wheel steering model and a single composite tyre model that combines Pacejka and Sector tyre models. The driver and standard mobility test manoeuvres available within Genrit do not cover all the current standard mobility tests such as soft soil slope slalom and the already noted programming limitation prevents the easy inclusion of these needed tests.

Genrit is also not able to make use of new computational capabilities such as flex-body which combines Finite Element Analyses (FEA) with multibody dynamics. Genrit cannot model the power train as part of the 3D model whereas this capability is inherent in current commercial software. Although the advantage this provides for the much longer simulation times is limited to complex terramechanics and does not support the power train development as efficiently as VBDrive. Genrit also cannot currently accommodate Discrete Element Modelling combined with FEA of the tyre. These two capabilities are currently leading the development of so-called advanced terramechanics.<sup>21</sup>

The SAAMM functionality was programmed in ArcGIS® version 9.0 using Visual Basic for Applications (VBA) which is no longer recognised within most current ArcGIS® versions. Thus, SAAMM requires substantial recoding to enable it to run in later versions of ArcGIS®. ArcGIS® 9.0 is no longer supported and is particularly problematic when trying to import data collated and parameterised in newer versions of ArcGIS® into SAAMM.

The biggest limitation of the MOBSIM suite however is that its existence and consequently its capabilities and the added value it can bring, are not well known amongst its primary users, the SANDF and Armscor. Some modules of MOBSIM have been, and are still being, used by local South African defence industries in the development of protected vehicle systems for both local and international markets. However, when compared to the less capable NATO-equivalent program, NRMM, which is used extensively across both the USA industry and USA military vehicle mobility research and evaluation, planning and geospatial organisations, MOBSIM is barely utilised in South Africa. The

use of NRMM to verify offered vehicles' performance is mandated as part of the USA military acquisition process, the similar use of MOBSIM locally could substantially enhance the SANDF decision-making process.

## Future Developments

The limitations posed by MOBSIM in meeting current and future defence vehicle modelling needs are primarily due to the age of the software suite rather than any real technical shortcomings. The speed with which useable model data is generated is advantageous when quick answers are required or a large number of options or scenarios must be modelled. The fundamental functionality that MOBSIM provides is still valid and can be enhanced with relatively simple incremental improvements.

The structure of MOBSIM is still valid. However, it is important that MOBSIM be upgraded to ensure this functionality is maintained and its use and application are expanded within both local defence industries, as well as within Armscor and the SANDF. The initial updates will be to ensure a more robust software platform to accommodate current and future operating software upgrades, as well as address most of the smaller technical limitations noted above. The upgrades will focus on verifying and validating the simple terramechanics models through expanded research on tyre-soil interaction based on the Bekker-Wong and Janosi-Hanamoto equations. This research appears to have been neglected due to the wider acceptance and application of the CI for military vehicle mobility predictions. It is thought this is due to the simplicity and ease of obtaining CI data, as well as what appears to be generally acceptable results obtained from applying CI-derived mobility performance. Based on the NATO Applied Vehicle Technology (AVT) 248 Research Task Group (RTG) New Generation NATO Reference Mobility Model (NG-NRMM) work there is an international resurgence in research pertaining to the validity and the application of the Bekker-Wong and Janosi-Hanamoto models to address the practical limitations of the CI such as slippery soils.

Using the same terramechanics research outputs, the development, verification and validation of a Finite Element tyre model and Discrete Element Modelling soil model should be implemented. This approach mimics the complex terramechanics being introduced as part of the New Generation NATO Reference Mobility Model (NG-NRMM) project. Here complex terramechanics is understood to mean a full physics-based model of the soil-tyre interaction and resultant tractive-effort generated on a particle level. Simple terramechanics is seen as simplified models using empirically based soil parameters derived from in-situ measurements. The advanced terramechanics

capability will enhance the capability to understand and predict wheeled and tracked vehicle performance in a range of soft soils and investigate factors that influence this performance. Issues such as moisture content on tractive effort can be explored and used in conjunction with soil moisture migration models to research the influence of weather patterns in potential areas of operation and generate mobility maps indicating go/no-go areas, maximum and average speed maps, etc.

With the complex terramechanics, the modelling and prediction of vehicle mobility in areas where soil data and parameters may not be available will become a powerful tool. This tool will enable the modelling of a range of soils and vegetation with the output being a series of vehicle mobility predictions and performance limits that can be expected. This information can assist deployment planning, as well as develop or evaluate technologies needed to address mobility shortcomings. The particle-physics-based soil models will provide critical understanding of the factors that must be measured and addressed through research to better understand and enhance vehicle mobility and to digitally explore various mobility technologies and solutions. These areas of interest are typically soil moisture effects on generated tractive effort for different soils, moisture migration, embedded objects, etc. These modelling outputs can then lead to enhanced vehicle system acquisition requirements and/or technology projects to develop solutions.

The introduction of the complex terramechanics capability will require the integration of advanced commercial multibody dynamics software, such as MSC Software ADAMS<sup>®</sup>,<sup>22</sup> into MOBSIM. This will provide leading-edge graphic representation of the systems being modelled, as well as improved graphic user interfaces, improved model development times and capabilities such as flex-bodies resulting in better accuracy. Other functionality introduced with this software platform will be the ability to model engines, engine control systems, active suspensions, braking systems, as well as intelligent vehicle systems including modelling sensors used for intelligent and autonomous vehicles, as a complete single system model.

This single enhancement will address a range of shortcomings with one implementation. Genrit however will still provide a simple set of standard MBD models for initial three-dimensional system performance results over a range of limited standard set of vehicle performance. As Genrit and the current MOBSIM suite do not require licencing fees, they can be distributed freely within the SANDF and Armscor to applicable users with any XP or later Windows<sup>®</sup> based computers.

One critical limitation of complex terramechanics is the computational power required. Currently, a five-second tyre-soil interaction FEA Discrete Element Modelling combination model takes around a week on international military high-performance computers.<sup>23</sup> This supports the need to keep the MOBSIM suite of simple terramechanics mobility calculations and modelling modules functional and useable. Despite this limitation, the benefits from the complex terramechanics models are enormous and thus will require modelling the vehicle's performance in advance over a range of terrains and soils. These outputs are then stored to be used when needed for quick tactical or scenario planning using the simple terramechanics models or used directly in the mapping module calculations. The complex terramechanics models can also be used to expand, enhance and verify the simple terramechanics models and thereby improve accuracy and range of soils they can be applied to.

The SAAMM module should be upgraded by converting the software to run on Java® or Python® scripts, enabling it to work with the current releases of ArcGIS®. Additional functionality will be introduced through the implementation of the NG-NRMM GIS Terrain and Mobility Mapping schema and, if required, modifications to suit SANDF needs. This schema enables the incorporation of various remote and in-situ measured data within the existing ArcGIS® database, allowing the SAAMM script to access and use the data, as well as return the performance data back into ArcGIS® for the generation of the required mobility maps and tabular performance data for each vehicle system modelled.

The SAAMM module should also be upgraded to include an urban manoeuvrability modelling and mapping capability. The final SAAMM upgrade envisioned at this time should be the inclusion of an uncertainty quantification functionality based on Kriging methods proposed by RAMDO Solution LLC.<sup>24</sup> This will enable the mobility maps to be generated based on a user-selected uncertainty level.

As noted by Box, “All models are wrong but some are useful”.<sup>25</sup> Thus to make the MOBSIM suite useful, it is imperative that a geo database be developed that supports the Discrete Element Modelling soil models. This will require additional soil parameters not regularly provided by most datasets such as triaxial and shear test data, CI and Bevameter data, as well as moisture content and presence of solid organic materials such as roots, etc. Following on from this and as critical as getting in-situ terrain data to support the Discrete Element Modelling soil models, will be verification and validation of vehicle models when deployed to be able to continuously improve and enhance the accuracy of the software.

## Conclusion

This chapter introduces the need and benefits of vehicle mobility modelling within the military environment and has presented the unique SANDF-developed mobility modelling software suite MOBSIM that was released in 2006. Although highly capable and technically equivalent to the latest versions of the NATO mobility modelling software NRMM [2016], MOBSIM has limitations. These limitations are both functionality losses due to operating platform upgrades, as well as technical capability as MOBSIM has not been updated and therefore has not kept up with newer, leading-edge software capabilities that has emerged.

Updates and improvements proposed to be introduced into MOBSIM have been presented and range from coding to make the software interoperable with current operating systems through to simple updates and the introduction of commercial leading-edge MBD software to enable soil and tyre interaction simulation with Discrete Element Modelling and FEA tyres (complex terramechanics). These improvements are partially based on the NATO NG-NRMM guidelines that will be modified to meet SANDF and Armscor requirements. As with South Africa, NATO has realised that the NRMM software introduced ca. 1979, does not harness the increased computing power along with enhanced mobility physics understanding we have today, even though it has been continuously updated.

Key to realising the performance potential and value added by the MOBSIM upgrade are a current, comprehensive and continually updated geo database and geo-technical models. As potential areas of deployment are both within and external to South Africa, this will require enhanced and innovative in-situ and remote sensing methods and equipment combined with existing techniques. To enable this required digital terramechanics database to be built will require collaboration, focused research, innovative application of existing and emerging measurement and parameterisation techniques and equipment along with the development of new technologies and terrain models from within the SANDF and Armscor, as well as the wider South African geosciences community. The benefits of these collaborative inputs will extend beyond the primary military application which is the focus of this chapter but have wider community impact across southern and central Africa.

It is hoped that this chapter will address the biggest shortcoming of MOBSIM by making its existence known amongst the potential user community and that knowledge of its existence and capabilities within Armscor and the SANDF will increase.



The author would like to note that he is in the privileged position of inheriting MOBSIM and is only tasked with maintaining and updating this capability and thus would like to acknowledge the following people who were the real driving force and developers of this software so many years ago: Mr. F.J. Beetge (Armcor), Dr. A.F. Naude (AFnet), Dr. N. van Niekerk (DVS), Dr. S. Nell (ADG Mobility) and Mr. P. Naude (Esteq).

## ENDNOTES AND REFERENCES

1. Naude, F.J. 2017. *History of the Development of MOBSIM*.; RMSS, 2001. *RSA-MIL-HDBK-62, Wheeled Vehicle Mobility: Design, Simulation, Test and Evaluation of; Handbook for*. 1<sup>st</sup> ed. South Africa: Armcor.
2. Wong, J.Y. 2010 *Terramechanics and Off-Road Vehicle Engineering*. 2<sup>nd</sup> ed. UK: Elsevier.; Bekker, M.G. 1969. *Introduction to terrain-vehicle systems*. 1<sup>st</sup> ed. Ann Arbor: University of Michigan Press.
3. Dasch, J.; Jayakumar, J.; Bradbury, M.; Gonzalez, R.; Hodges, H.; Jain, A.; Lagnemma, K.; Letherwood, M.; McCullough, M. & Priddy, J. n.d. PRE-RELEASE: Final Report ET-148 Next-Generation NATO Reference Mobility Model (NRMM). Warren, US Army TARDEC.
4. Murphy, N.R. & Randolph, D.D. 1993. A Limited NRMM Validation Study for ISTVS, Appendix to the Proceedings of the 11th International Conference of the ISTVS, Proceedings of the 11th International Conference of the ISTVS, 27-30 September 1993, ISTVS; NATO CSO, NATO CSO AVT-248 RTG Final Report.
5. AVT-248/RTG. 2017 – last update, Next-Generation NATO Reference Mobility Model (NRMM) Development.[Homepage of NATO STO] [Online]: Available: <https://scienceconnect.sto.nato.int/>
6. Ibid.
7. Naude, 2017, op. cit.
8. Rowland, D. & Peel, J.W. 1975. Soft Ground Performance Prediction and Assessment for Wheeled and Tracked Vehicles. In: *Proceedings of the Institute of Mechanical Engineers*, 205:75. London. Snyman, J.A. 1999. The LFPOC Leap-Frog Algorithm for Constrained Optimization. *An International Journal Computers and Mathematics with Applications*, 40:1085-1096. [https://doi.org/10.1016/S0898-1221\(00\)85018-X](https://doi.org/10.1016/S0898-1221(00)85018-X)
9. Naude, 2017, op. cit.
10. Ibid.
11. Ibid.
12. Ibid.
13. Ibid.
14. Wong, J.Y. 2010. *Terramechanics and Off-Road Vehicle Engineering*. 2<sup>nd</sup> ed. UK: Elsevier.; Bekker, M.G. 1969. *Introduction to terrain-vehicle systems*. 1<sup>st</sup> ed. Ann Arbor: University of Michigan Press.

15. Naude, 2017, op. cit.
16. Wong, 2010, op. cit.;  
Bekker, 1969, op. cit.
17. Naude, 2017, op. cit.
18. Wong, J.Y. 2001. *Theory of Ground Vehicles*. 3<sup>rd</sup> ed. United States of America: John Wiley and Sons.
19. Naude, F.J. 2008. Software code developed for VB Drive. Unpublished code, Pretoria, Armscor.
20. Dasch et al. n.d, op. cit.
21. No Author. n.j. *The Multibody Dynamics Simulation Solution*. [Online]: <http://www.mscsoftware.com/product/adams> [Accessed 21 March 2017]
22. Wasfy, T. 2017. *Advanced Science Associates Dynamic Interactions Simulator*.
23. NATO CSO, n.d. NATO CSO, n.d. AVT-248 RTG Final Report.
24. Box, G.E.P. 1979. *Robustness in the Strategy of Scientific Model Building*. Madison: Academic Press.

# The Influence of Geographic Factors on the Distribution of Natural Radionuclides



# 8

Jacques Bezuidenhout, Hennie Smit & Alwyn Geyser 

## Introduction

Sources of naturally occurring radiation were formed during the formation of the earth and have since then been present in the physical environment.<sup>1</sup> These sources of naturally occurring radiation are Potassium 40 ( $^{40}\text{K}$ ), Uranium 238 ( $^{238}\text{U}$ ) and Thorium 232 ( $^{232}\text{Th}$ ). They are classified as primordial radionuclides. Primordial radionuclides are also referred to as “natural radionuclides”. Trace quantities of these elements, together with their daughter nuclides, exist in all types of rocks and soil. The activity concentrations of  $^{40}\text{K}$ ,  $^{232}\text{Th}$  and  $^{238}\text{U}$  and their daughters in soil are therefore dependent on the geology of the parent material from which the soil originated.<sup>2</sup> The level of radioactivity consequently relate to the type of rock and its mineral composition.



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Granite contains admixtures of  $^{40}\text{K}$ ,  $^{232}\text{Th}$  and  $^{238}\text{U}$  and compared to other rock types contains relatively high concentrations of radioelements.<sup>3</sup> It can therefore be inferred that soil originating from granite will bear a similar radioactive signature. The concentrations of the natural radionuclides may include daughter nuclides that emit gamma  $\gamma$ -ray photons with characteristic intensities and energies ranging from keV to MeV.<sup>4</sup>

Gamma-ray emissions of these natural radionuclides, are measurable with a detector which makes it possible to map the variations in the distribution of natural radiation. By mapping variations in the concentration of natural radionuclides it is possible to create radioelement maps that can be used during qualitative analysis. The qualitative analysis aimed to establish the influence of identified geographic factors on the spread of natural radionuclide concentrations in the study area.

## The Study Area

The lithology of the West Coast is dominated by 600-650 million-year-old shale. Millions of years of erosion caused the overlying shale to erode, thus exposing the underlying granite. The granite outcrops are an estimated 500 million years old and form part of the Cape Granite suite.<sup>5</sup> The concentration levels of the natural radionuclides within these igneous granite outcrops are determined by the geological processes by which they were formed. In turn, these igneous granite outcrops determine the natural radiation concentration levels of the soil produced from these rocks. Igneous rocks contain relatively high concentrations of natural radionuclides which in turn contribute to similarly high levels of natural radionuclides within the soil surrounding these outcrops.<sup>6</sup>

The exposed granite outcrops on the West Coast of South Africa have been exposed to weathering and erosion for millions of years. This implies that the topsoil within the areas surrounding the granite outcrops consists mainly of weathered granite particles. These soils should also then bear the same radiation signature as the surrounding granites. The Saldanha Bay Military Area (SMA) is situated on the West Coast of South Africa (figure 8.1). The SMA houses three granite outcrops: Malgaskop, Baviaansberg and Môresonkop. These granite hills form part of the Cape Granite suite.<sup>7</sup> Figure 8.1 also indicates the positions of Baviaansberg and Malgaskop within the research site. Baviaansberg was identified as the research site as it is uniquely situated so that the prevailing winds are onshore with little land between the ocean and the hill. The prevailing winds are north-westerly in winter, and south-easterly in summer.<sup>8</sup> Consequently, little Aeolian deposition from outside the area takes place and the radiation signature is almost exclusively dependent on the geology of the area.



FIGURE 8.1 Google Earth image indicating the position of Saldanha Bay on the West Coast of South Africa. The area of the Saldanha Bay Military Area is indicated by the green polygon and the study area by the blue rectangle.<sup>9</sup>

The major phase of human activity on and around Baviaansberg occurred during the Second World War, when buildings, bomb shelters and vantage points were erected. Some farming activity also occurred pre- and post-Second World War. Since the Second World War, the SMA has mostly been reserved for military training and other military activities. Currently, there are no substantial human activities taking place in or around the area, apart from an occasional military route march. Baviaansberg has therefore been unaffected by intense human activities for the past 40 years.<sup>10</sup> However, human activity is only one of the factors playing a role in the distribution of natural radiation in soil. Other geographic factors to consider are geology, topography, soil type, hydrology, and wind.

Because of the specific location of Baviaansberg and the prevailing wind directions there would have been little to no Aeolian deposition from outside the area. It is important to note that both prevailing wind directions are onshore conditions and reaches the research site with very little land between the shore and Baviaansberg. Overlying shale would also have further eroded away, whereas weathered and eroded granite would form the 'new' overlying soil. Aeolian deposits from distant geographic locations thus rarely occur on these outcrops. It was found that the surrounding soil immediately below the hills is mostly broken-down granite.<sup>11</sup>

Baviaansberg is a small hill with a height of 72 metres above mean sea level and a surface that is dominated by granite outcrops. The foot of Baviaansberg is 15 metres above mean sea level. It consists of three identifiable peaks, as indicated in figure 8.2, viz. the western, central and eastern peaks. Vegetation on Baviaansberg is classified as Saldanha Granite Strandveld that forms part of the Western Strandveld Bioregion, a section of the greater Fynbos Biome. The climate of the area is classified as Mediterranean with an average annual rainfall of 260 millimetres. The study area is adjacent to the Namaqualand desert region.<sup>12</sup>

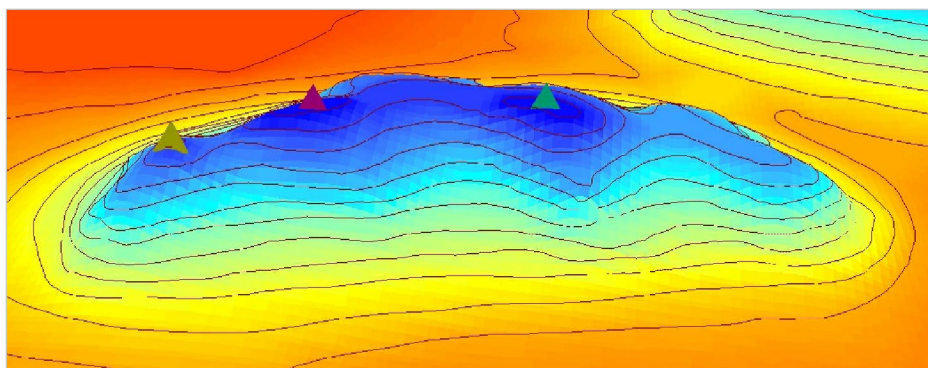


FIGURE 8.2 An elevated view of Baviaansberg with the eastern peak indicated by the turquoise beacon, the central peak by the purple beacon and the western peak by the yellow-green beacon

## Methodology

The system used for *in situ* measurements is the same setup developed and used by Bezuidenhout in 2012.<sup>13</sup> A Sodium Iodide Thallium Infused (NaI(Tl)) scintillation detector with a 7,62 x 7,62 centimetres crystal housed in an aluminium casing was used. This was coupled to a scintiSPEC Multi-Channel Analyser (MCA) that is produced by FLIR®.<sup>14</sup> The scintiSPEC MCA regulates the detector system operating voltage and signal communication via its USB connection. This setup was connected to a Trimble Yuma Rugged tablet PC.<sup>15</sup> The Yuma is equipped with an on-board GPS that provided an output of latitude, longitude and height above mean sea level. The entire detection setup is displayed in figure 8.3. Once the detector system was energy calibrated, the final data of the detector system was stored in the form of an energy spectrum. Energy calibrations were performed by using radiation sources with known energy peaks, similar to those used by Noncolela.<sup>16</sup>

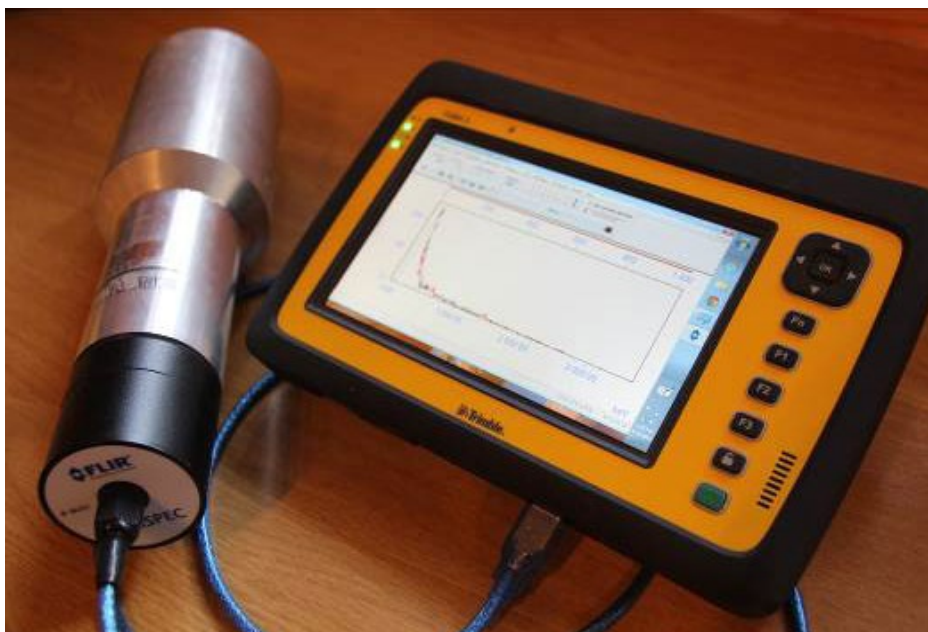


FIGURE 8.3 The detector system as used by Bezuidenhout<sup>17</sup>

A systematic sampling design was followed to determine the measurement positions before any field measurements commenced.<sup>18</sup> The research site was demarcated by creating a fishnet grid, using ArcMap, over Baviaansberg on a 1:50 000 map with grid reference 3317BB (see figure 8.4).



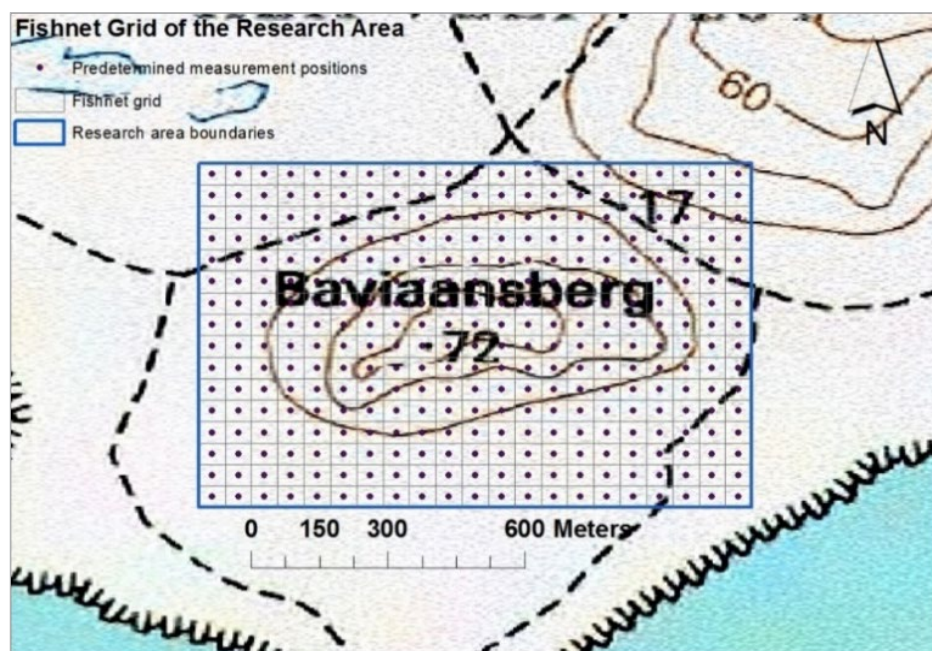


FIGURE 8.4 Fishnet grid and predetermined measurement positions of the research site

WinTMCA32 software was used to perform energy calibrations. Sources used to perform the energy calibrations were  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  nuclides. The instrument was exposed to a drift error due to exposure to ambient temperatures. All *in situ* energy spectra were again calibrated individually to accommodate for said drift. During post calibration the energy peaks of the primordial radionuclides or a daughter radionuclide thereof were used.

In order to extract the radiation concentration levels Full Spectrum Analyses (FSA) were performed on the spectra. The concentrations of the natural radionuclides in the soil were measured and mapped by means of *in situ*  $\gamma$ -ray photon measurements. Separate radioelement maps for  $^{40}\text{K}$ ,  $^{238}\text{U}$  and  $^{232}\text{Th}$  were constructed in ArcMap by using the activity concentrations associated with each measurement position. These radioelement maps were constructed in ArcMap through ordinary Kriging and thin plate splines.

However, in terms of the research, ordinary Kriging was chosen as the interpolation method for creating radioelement maps as was suggested by the International Atomic Energy Agency (IAEA). Ordinary Kriging also provides a visual 'smoothness' of the image. The main reason for using ordinary Kriging is that it takes into account the stochastic nature of radioactive decay, superimposes it on the spatially dependent



signal in the measurements during interpolation, and calculates new values for the measurement positions which is something thin-plate splines are incapable of doing.<sup>19</sup> The radioelement maps for  $^{40}\text{K}$ ,  $^{238}\text{U}$  and  $^{232}\text{Th}$  were also analysed using various GIS techniques. Qualitative data analysis of concentration levels of natural radiation and geographic factors were then used to research the influence of geographic factors on the distribution of natural radiation.

The raster calculator function in ArcMap was used to create a new raster layer as an experiment in order to identify areas where the predicted data differs from the actual data. This layer was created by subtracting the ordinary Kriging results from the thin-plate splines. This process produced a raster that highlighted the areas that displayed some form of spatial irregularity with regard to respective data points. Another method used to analyse the data was to compile rasters that indicated the ratio in concentrations between the three radionuclides. This was done with the raster calculator in ArcMap. The three ratios used in creating the new rasters were  $^{232}\text{Th}/^{40}\text{K}$ ,  $^{238}\text{U}/^{40}\text{K}$  and  $^{238}\text{U}/^{232}\text{Th}$ . The resultant layers and radioelement maps were used for further qualitative analysis.

A 5 metre contour map was also imported into ArcMap and then georeferenced.<sup>20</sup> The contours and coastline of the research site were digitised and a DEM was created. The DEM was used to create a flow accumulation raster and a slope raster. The DEM was then imported into ArcScene to create a three-dimensional model of the area and, in conjunction with the radioelement maps, a flow accumulation raster and slope DEM were used for further qualitative analysis. All rasters created were also imported to Google Earth for qualitative analysis. A slope profile for the northern and southern slopes of Baviaansberg was also created. An additional layer was added for human activities in order to compare the influence of human activities of the area to the various rasters.

A total of 336 measurements were recorded in the research site. The results of the concentrations of the  $^{40}\text{K}$ ,  $^{232}\text{Th}$  and  $^{238}\text{U}$  will be discussed in terms of high, intermediate and low levels. Figure 8.5 provides an example of the method followed to obtain the values for  $^{40}\text{K}$ .

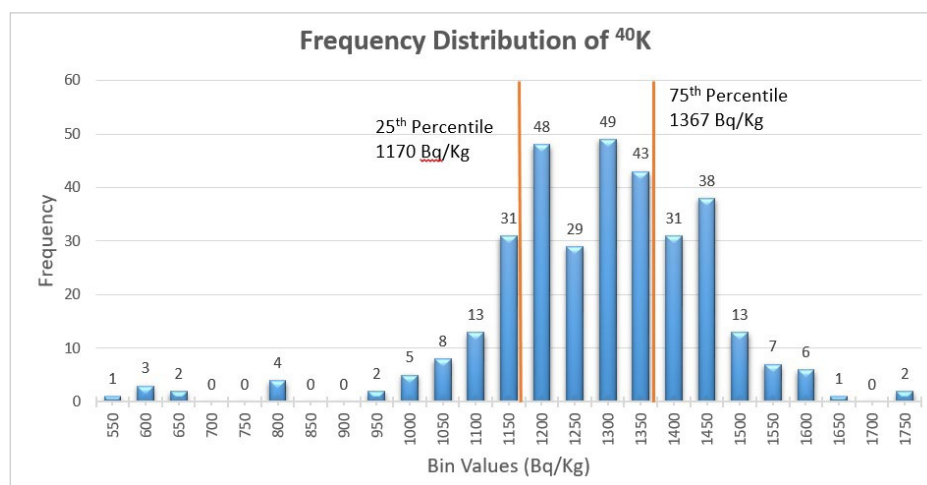


FIGURE 8.5 The  $^{40}\text{K}$  concentration measurements. Red lines indicate the positions of the 25<sup>th</sup> and 75<sup>th</sup> percentiles.

It was decided that, according to figure 8.5, low concentrations of  $^{40}\text{K}$  would be values from the 25<sup>th</sup> percentile and lower, intermediate  $^{40}\text{K}$  concentrations would range between the 25<sup>th</sup> and 75<sup>th</sup> percentile and high  $^{40}\text{K}$  concentrations from the 75<sup>th</sup> percentile and higher. The values for low  $^{40}\text{K}$  concentrations are from 1 170 Bq/kg and lower, 1 171 Bq/kg to 1 366 Bq/kg for intermediate  $^{40}\text{K}$ , and 1 367 Bq/kg and higher for high  $^{40}\text{K}$  concentrations. The method for determining the high, intermediate and low values is the same as those described by the Stanford School of Medicine.<sup>21</sup> The same method was followed with  $^{232}\text{Th}$  and  $^{238}\text{U}$ .

## Results

Figure 8.6 illustrates the distribution of concentrations of  $^{40}\text{K}$  in the research site. According to figure 8.6, the highest  $^{40}\text{K}$  concentrations of 1 400-1 501 Bq/kg are found in the north-eastern corner of the research site, north-east of the eastern peak of Baviaansberg. This area is situated between Baviaansberg and neighbouring Malgaskop.

The lowest  $^{40}\text{K}$  concentrations of 653 85-1 030 Bq/kg are situated in the south-eastern corner of the research site, south-east of the eastern peak. There are also two areas on the northern slope of Baviaansberg that display higher  $^{40}\text{K}$  concentrations of 1 350-1 450 Bq/kg which are situated on the southern slope of Baviaansberg, south-east of the central peak. The area on the southern boundary of the research site, south south-west of the eastern peak, shows lower  $^{40}\text{K}$  concentrations of 1 086-1 184 Bq/kg. It is further important

to note the general trend in distribution of  $^{40}\text{K}$  concentrations on Baviaansberg, with the northern slope exhibiting more areas with higher  $^{40}\text{K}$  concentrations, as well as generally higher  $^{40}\text{K}$  concentrations than on the southern slope. There is also a gradual decrease in  $^{40}\text{K}$  concentrations downslope from areas that exhibit higher  $^{40}\text{K}$  concentrations.

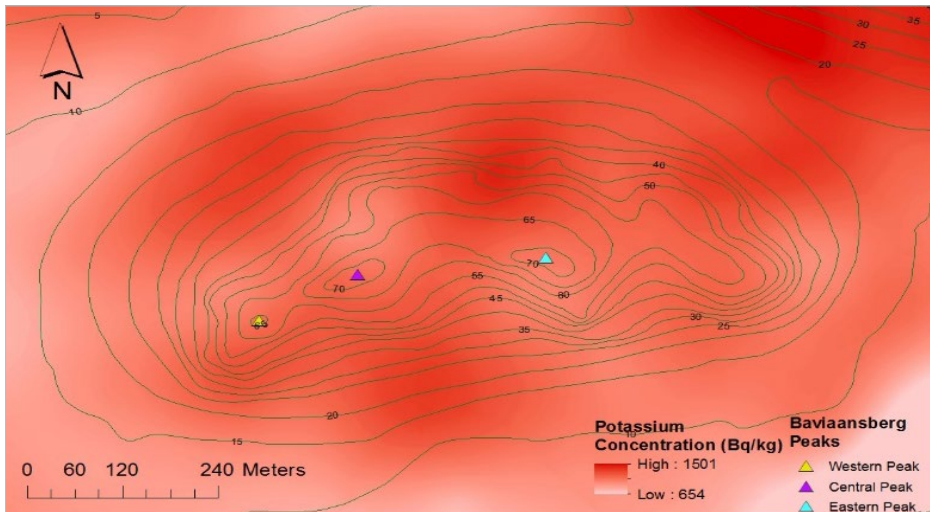


FIGURE 8.6 The distribution of  $^{40}\text{K}$  concentrations as an overlay on the contour map of Baviaansberg. The  $^{40}\text{K}$  concentrations differ between 654 Bq/kg and 1 501 Bq/kg.

Figure 8.7 indicates the spatial distribution of concentrations of  $^{232}\text{Th}$  across the research site. In figure 8.7 the areas of high  $^{232}\text{Th}$  concentrations (80-112 Bq/kg) are situated on the northern, eastern and north-eastern slopes of Baviansberg. These areas are north of the central peak, from directly north of the eastern peak to east south-east of the eastern peak, and south south-east of the eastern peak.

There are areas of intermediate to high  $^{232}\text{Th}$  concentrations, 71-81 Bq/kg, on the south-western and western slope, that is south of the central peak to west north-west of the western peak. The lower concentrations of 23-63 Bq/kg, are all situated downslope from the 15 metre contour.

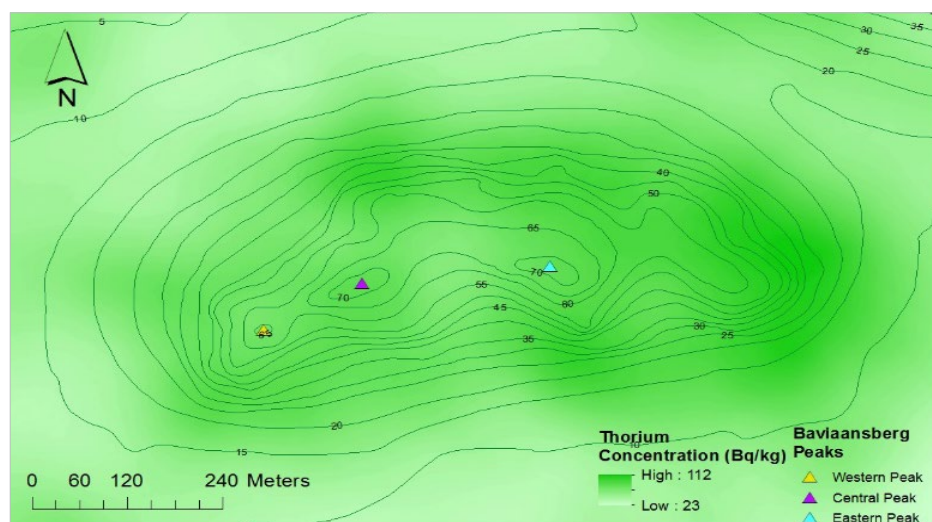


FIGURE 8.7 The distribution of  $^{232}\text{Th}$  concentrations as an overlay on the contour map of Baviaansberg. The  $^{232}\text{Th}$  concentrations differ between 23 Bq/kg and 112 Bq/kg.

Two areas on Baviaansberg exhibit intermediate  $^{232}\text{Th}$  concentrations that are lower than the surrounding  $^{232}\text{Th}$  concentrations. The first area is the valley in the centre of the southern slope, south east of the central peak, with concentrations of 59-70 Bq/kg. The second area is situated on the north western slope, north north-west of the western peak, with concentrations of 43-72 Bq/kg. Differences in  $^{232}\text{Th}$  concentrations are attributed to various geographic factors.

Figure 8.8 represents the  $^{238}\text{U}$  concentrations of the research site. The lower to intermediate  $^{238}\text{U}$  concentrations, 11-33 Bq/kg, are all situated around Baviaansberg from the 15 metre contour downslope. There are two exceptions. The first exception is in the north-east corner of the research site, north-east of the eastern peak. This area is situated between Baviaansberg and the neighbouring Malgaskop and exhibits intermediate  $^{238}\text{U}$  concentrations of 35-44 Bq/kg. The second exception is the valley in the middle of the southern slope, east to south-east of the central peak, and exhibits intermediate  $^{238}\text{U}$  concentrations of 37-43 Bq/kg. The differences in  $^{238}\text{U}$  concentrations are attributed to the various geographic factors. As was previously mentioned, granite in general bears high concentrations of natural radionuclides compared to other rocks.

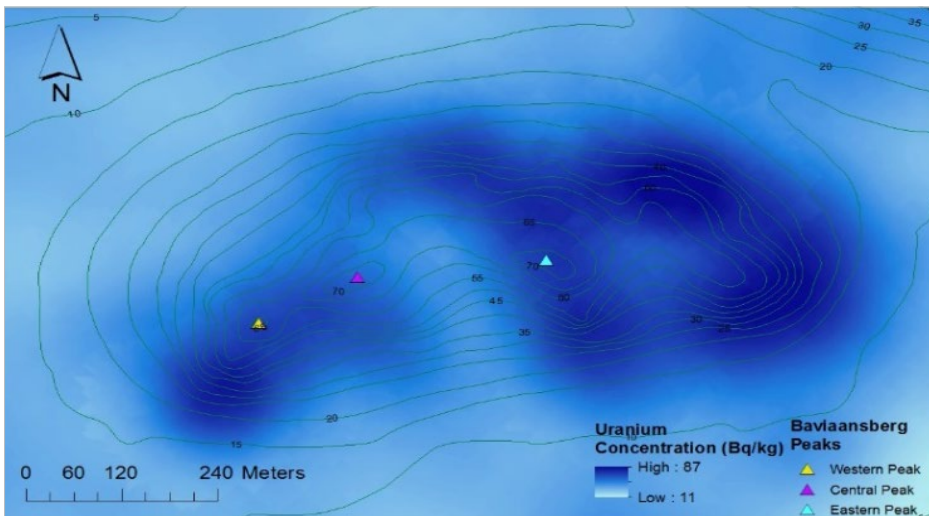


FIGURE 8.8 The distribution of  $^{238}\text{U}$  concentrations as an overlay on the contour map of Bavianaansberg.  $^{238}\text{U}$  concentrations differ between 11 Bq/kg and 87 Bq/kg.

## Discussion

Figure 8.9 shows the location of granite outcrops on Bavianaansberg and if the locations are compared to figures 8.6, 8.7 and 8.8 it is clear that the areas around the granite outcrops correlate well with the higher concentrations of  $^{40}\text{K}$ ,  $^{232}\text{Th}$  and  $^{238}\text{U}$ .

Soil originating from these granite outcrops should also then bear a radiation signature of similar concentrations to the granite outcrops from Bavianaansberg. Results from this research indicate that the highest concentrations of  $^{40}\text{K}$ ,  $^{232}\text{Th}$  and  $^{238}\text{U}$  are measured on and around the granite outcrops. This supports the proposition that the geology of an area influences the radiation signature of the parent material directly, which again affects the natural radionuclide concentrations of the soil.<sup>22</sup>

When comparing the  $^{40}\text{K}$  concentrations in figure 8.6 to the slope raster of figure 8.10, it seems that the areas of higher  $^{40}\text{K}$  concentration are situated directly below the areas of steep slope. These areas coincide with areas directly below the granite outcrops.



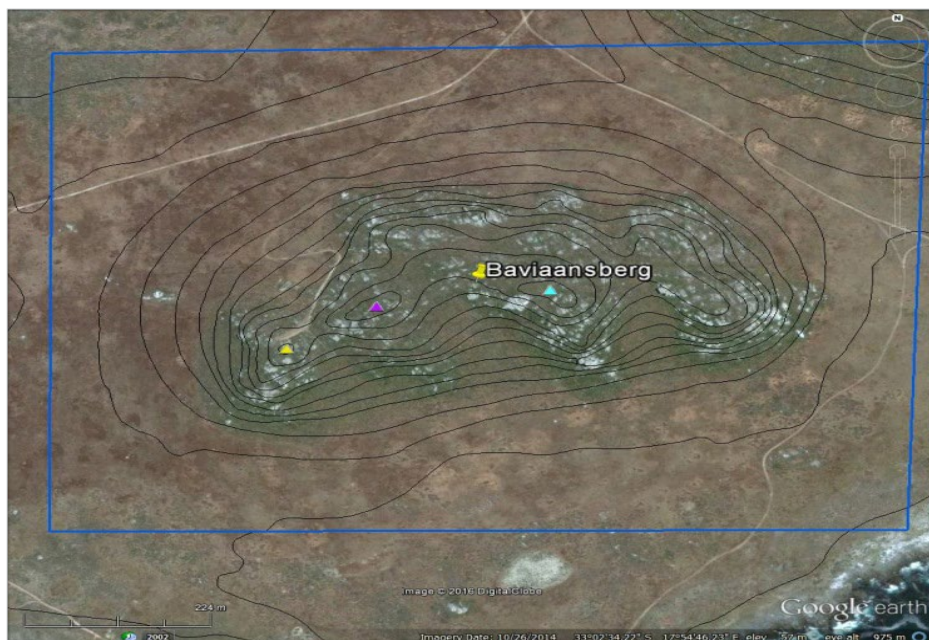


FIGURE 8.9 A Google Earth image that shows the granite outcrops of Baviaansberg

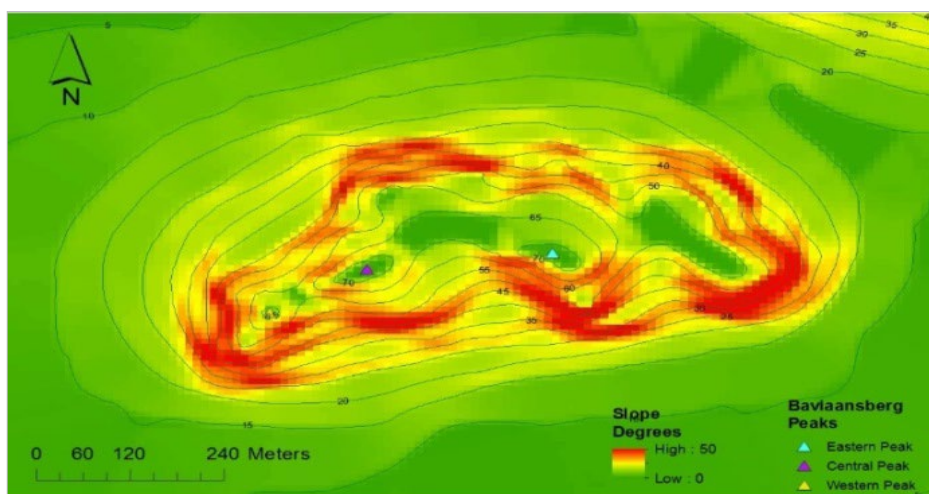


FIGURE 8.10 A slope raster of Baviaansberg

The reason for the higher  $^{40}\text{K}$  concentrations in these areas is the fact that the weathered granite particles concentrate directly below the granite outcrops.<sup>23</sup> These weathered particles contain  $^{40}\text{K}$  radionuclides, and accumulate at the bottom of the granite outcrops.

The accumulation of particles around granites increase the amount of  $^{40}\text{K}$  radionuclides in the surrounding soils. This accumulation in turn increases the concentrations of  $^{40}\text{K}$ . The larger weathered particles will be situated close to their parent material, thus providing the soil closer to the parent material with virtually the same radiation signature as the parent material. As the distance away from parent material increases, the size of the weathered particles decreases. Once overland flow or stream flow starts to occur, the weathered particles will be transported further away, hence the gradual decrease of  $^{40}\text{K}$  concentrations downslope from the granite outcrops.<sup>24</sup> This happens because of two processes. Soluble materials (including soluble radionuclides) will be carried in solution, while less soluble material will be transported mainly in suspension or through saltation and traction.<sup>25</sup> When the flow decrease in intensity or volume, the larger particles (usually those transported through saltation and traction) will be deposited first. Particles in suspension will be transported further from the source and those in solution, the furthest. In the study area overland flow is responsible for the majority of sediment transport with virtually no well-developed streams present.

The northern slope of Baviaansberg shows a greater number of areas of high  $^{40}\text{K}$  concentrations in comparison to the southern slope. It can be seen from the slope raster that the southern slope is steeper than the northern slope. Overland flow on the southern slope will thus occur faster than on the northern slope due to the difference in steepness. Slower overland flow causes the deposition of particles from the overland flow to occur closer to the parent material and at a more regular rate on the northern slope than on the southern slope. Deposition of particles containing  $^{40}\text{K}$  radionuclides on the northern slope will subsequently occur closer to the parent material and at more regular intervals. Results from this research indicate a possible relationship between slope and the spread of  $^{40}\text{K}$  concentrations. This relationship corroborates the work done by Marshak.<sup>26</sup>

Granite has naturally higher concentrations of  $^{232}\text{Th}$ , which in turn also causes the soil surrounding the granite to bear the same level of  $^{232}\text{Th}$  concentrations.<sup>27</sup> This can be seen where the steep slopes of Baviaansberg correspond to the areas of higher  $^{232}\text{Th}$  concentrations if figures 8.7 and 8.10 are compared. As mentioned earlier, the areas of steep slope are associated with granite outcrops. From these outcrops the granites are weathered and eroded and the smaller pieces of granite containing  $^{232}\text{Th}$  radionuclides are removed from the parent material. As these weathered particles are removed from the parent material they are dispersed over a larger area. This in turn causes a decrease in the  $^{232}\text{Th}$  concentrations, as shown in figure 8.7.

The  $^{238}\text{U}$  concentration distribution pattern is similar to the distribution pattern of  $^{232}\text{Th}$ . The distribution pattern of  $^{238}\text{U}$  concentrations also follows the same principles as that of  $^{232}\text{Th}$  concentrations. The only notable difference in the distribution patterns of  $^{238}\text{U}$  and  $^{232}\text{Th}$  is in the valley of the southern slope of Baviaansberg, east to south-east of the central peak. The valley portrayed in figure 8.10 shows a greater decrease in  $^{238}\text{U}$  concentrations than that of  $^{232}\text{Th}$  concentrations. This means that  $^{238}\text{U}$  radionuclides are removed from the soil more easily than  $^{232}\text{Th}$  radionuclides. This removal process is supported by Ruffel et al.<sup>28</sup> The slope raster also reveals that the southern slope contains the most steep slope areas, as confirmed by slope profiles created from the five transects drawn across Baviaansberg.

The southern slope of Baviaansberg houses more areas of high  $^{232}\text{Th}$  and  $^{238}\text{U}$  concentrations than the northern slope (figures 8.7 and 8.8). It indicates once more that  $^{232}\text{Th}$  and  $^{238}\text{U}$  are less soluble than  $^{40}\text{K}$ . In this case the  $^{40}\text{K}$  radionuclides are removed more readily from the steeper southern slope than from the northern slope, leaving behind more  $^{232}\text{Th}$  and  $^{238}\text{U}$  radionuclides. These findings are verified by figures 8.11a-b. Figure 8.11a shows the ratio of  $^{232}\text{Th}$  to  $^{40}\text{K}$  in the research site and figure 8.11b the ratio of  $^{238}\text{U}$  to  $^{40}\text{K}$ .

When figures 8.11a-b are compared, it appears that the high ratios of  $^{232}\text{Th}$  to  $^{40}\text{K}$  are spread over a larger surface area than the ratio of  $^{238}\text{U}$  to  $^{40}\text{K}$ , as  $^{238}\text{U}$  will be removed more regularly from granite outcrops. This causes the  $^{238}\text{U}$  to be spread over a larger area than  $^{232}\text{Th}$ . This in turn causes a greater concentration of  $^{232}\text{Th}$  radionuclides around the granite outcrops compared to  $^{238}\text{U}$  radionuclides. These results also support the work of Ruffel et al. through which  $^{238}\text{U}$  is reported to be more soluble than  $^{232}\text{Th}$  and can thus be transported further afield.<sup>29</sup>

Ramli found that soil type determines the level of natural radionuclide concentrations present in soil.<sup>30</sup> The soil layer classified as “fine to coarse sandy soils, coquina and granite outcrop” is associated with lower concentrations of  $^{40}\text{K}$ ,  $^{232}\text{Th}$  and  $^{238}\text{U}$ , as seen in figure 8.12a-c.



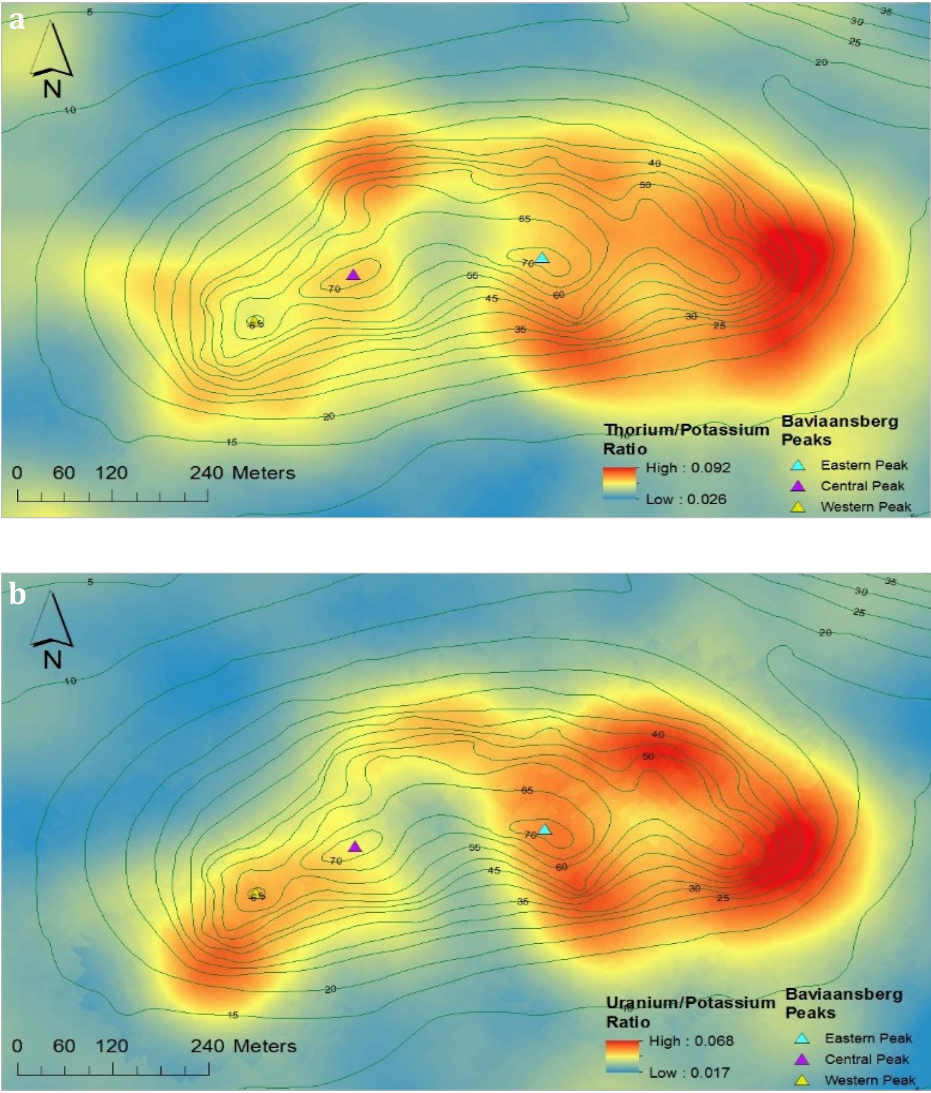
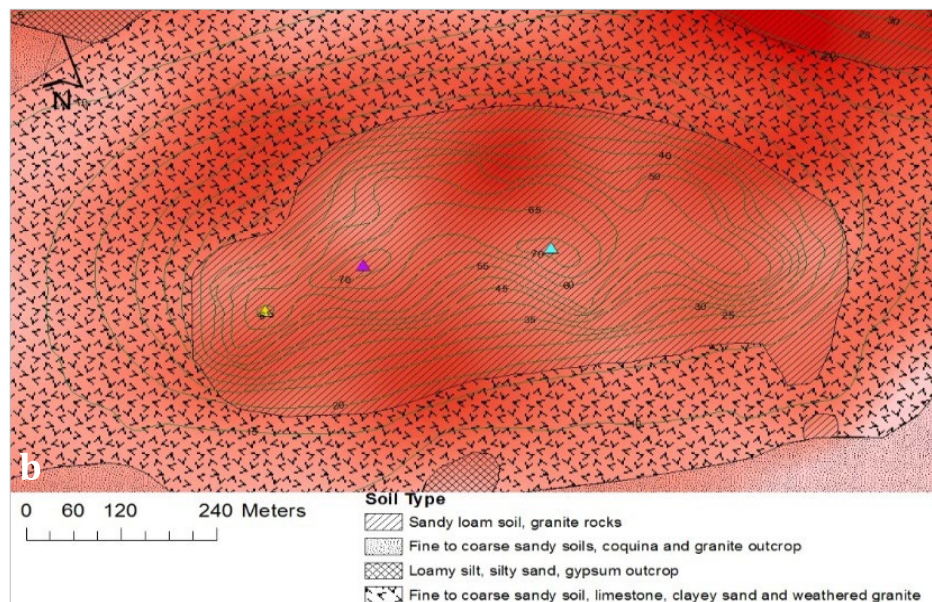
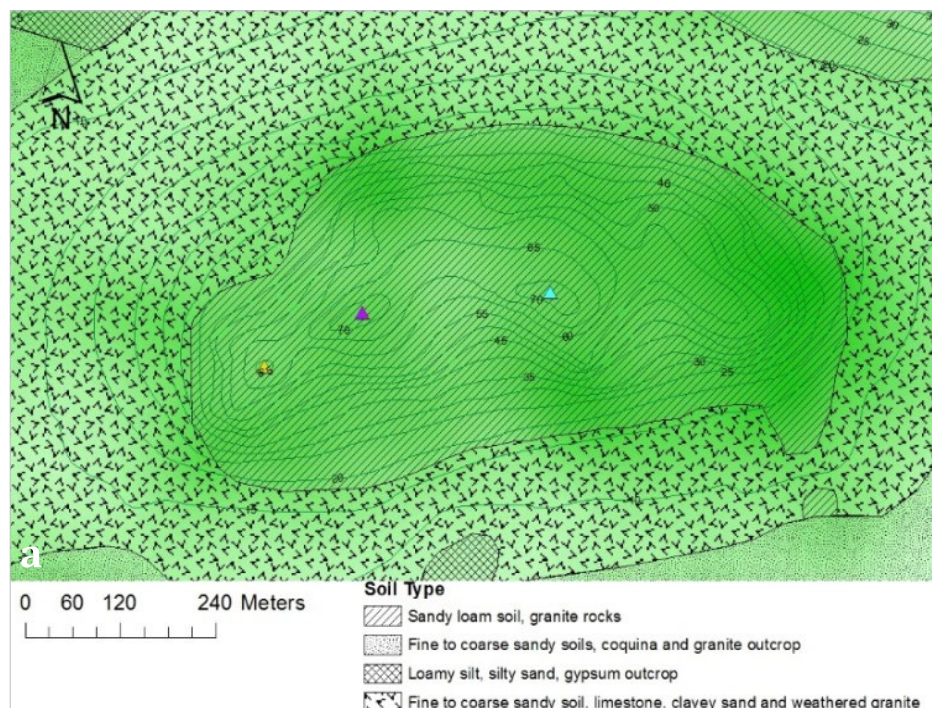


FIGURE 8.11 (a-b): The ratio of distribution of  $^{232}\text{Th}$  to  $^{40}\text{K}$  concentrations and the ratio of distribution of  $^{238}\text{U}$  to  $^{40}\text{K}$  as overlays on the contour map of Baviaansberg





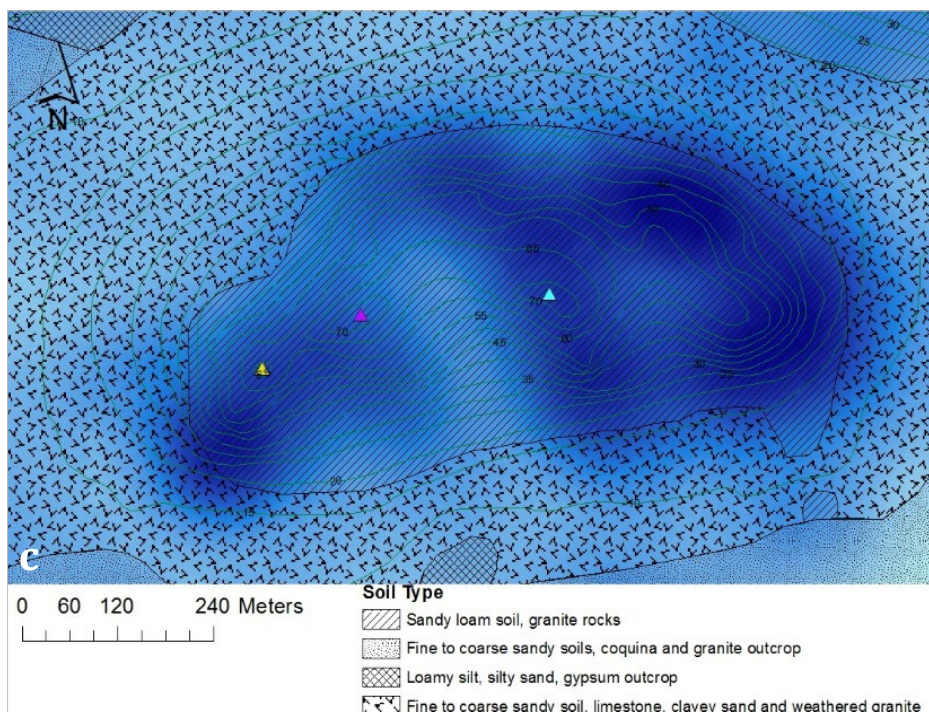


FIGURE 8.12 (a-c): Soil types as an overlay on the radioelement maps of  $^{40}\text{K}$ ,  $^{232}\text{Th}$  and  $^{238}\text{U}$ <sup>31</sup>

The reason for the lower concentrations of  $^{40}\text{K}$  in the “fine to coarse sandy soils, coquina and granite outcrop” soil layer is its physical structure and composition. Coquina is an indication of the presence of broken shell and limestone. Even though granite outcrop is part of the soil layer name, there are no granite outcrops within this soil layer in the research site. This soil layer is also the furthest away from its parent material – the granite outcrops on Baviaansberg. This means that the further the soil particles are transported away from the parent material, the more they disperse and the more external materials are added. During field measurements the presence of marine deposits in this soil layer was noted as confirmation of the addition of external material. The addition of such external materials further decreases the  $^{40}\text{K}$ ,  $^{232}\text{Th}$  and  $^{238}\text{U}$  concentrations. Soil in this area also contains more biological components in its composition. This was confirmed during field measurements. An addition of biological matter to soil will further decrease the concentrations of  $^{40}\text{K}$ ,  $^{232}\text{Th}$  and  $^{238}\text{U}$ . Soil with a higher quantity of biological matter present is also generally associated with lower concentrations of  $^{40}\text{K}$ .<sup>32</sup> The coarse sandy structure of this soil layer also contributes to the lower concentrations of  $^{40}\text{K}$ ,  $^{232}\text{Th}$  and  $^{238}\text{U}$ . The particles containing  $^{40}\text{K}$ ,  $^{232}\text{Th}$  and  $^{238}\text{U}$  radionuclides that reach these sandy areas by way of solution in overland flow will not be deposited, but will filter away

through soil due to high infiltration rates associated with coarse sandy soils. There is also a relationship between high concentrations of  $^{232}\text{Th}$  and  $^{238}\text{U}$  that is associated with the 'sandy loam soil, granite rocks' soil layer. This relationship between the high concentrations of  $^{232}\text{Th}$  and  $^{238}\text{U}$  and the 'sandy loam soil, granite rocks' soil layer is due to high levels of  $^{232}\text{Th}$  and  $^{238}\text{U}$  associated with granite outcrops and soil formed from these outcrops.

Water is the factor that has the largest influence on the physical landscape development on Earth.<sup>33</sup> Soil and weathered particle distribution are mostly dependent on the water flow over an area.<sup>34</sup> Figure 8.13 is a flow accumulation raster of the research site.

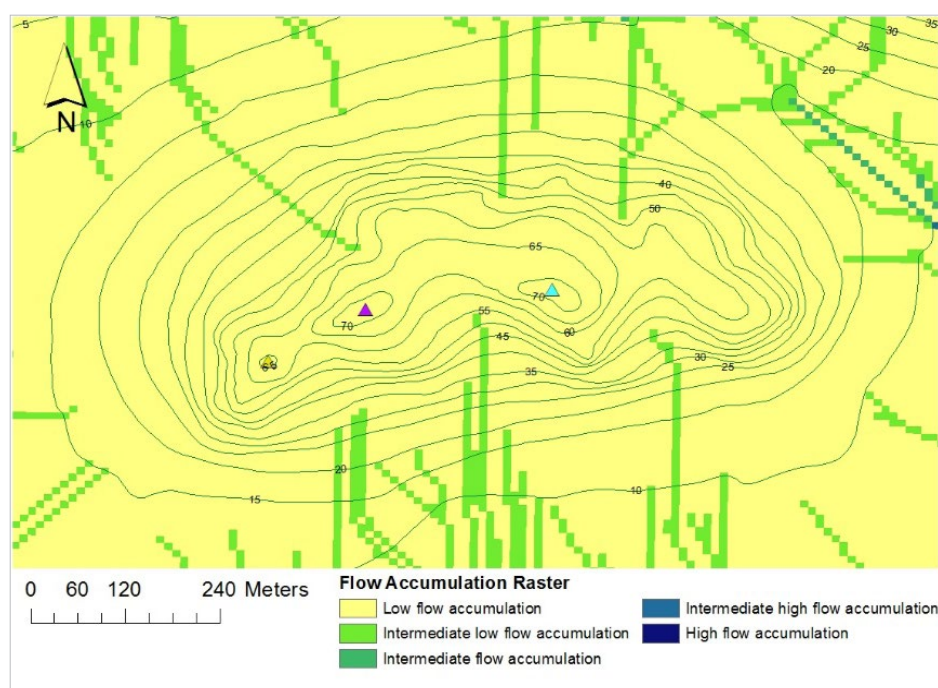


FIGURE 8.13 The flow accumulation raster as an overlay on the contour map of Baviaansberg

The flow accumulation raster was generated from a DEM created by digitising the contours from an orthophoto series map of the research site. The flow accumulation is an indication of the amount of cells in the raster image that will flow into it. In this case the values of each cell are associated with the height above mean sea level according to the DEM. The flow accumulation raster calculates the number of upstream cells that will account for the drainage into each cell.<sup>35</sup> The flow accumulation raster can be considered as an indication of where deposition is more likely to occur during overland flow.

Overland flow is the main type of water flow within the research site since there are no pertinent streams and rivers in the research site. Overland flow becomes stagnant quicker than streamflow. It is worth noting that the majority of the intermediate to high flow accumulation areas lie below the 20 metre contour. These lower lying areas also correlate with the areas of gentle slope. This is an indication that these lower lying areas are the areas where the overland flow accumulates and where flow is likely to stagnate. These are the areas where deposition is most likely to occur. The flow accumulation raster can thus be viewed as a proxy deposition raster. The areas that indicate intermediate low to high flow accumulation are also the areas in which deposition is most likely to occur.

Upon comparison of figures 8.6 and 8.13, the hydrological impact on the distribution of  $^{40}\text{K}$  concentrations becomes noticeable. The spread of concentrations of  $^{40}\text{K}$  on Baviaansberg shows an inversely proportional relationship to the degree of slope. The areas with a steep slope coincide with concentrations of  $^{40}\text{K}$  of 1 211-1 351 Bq/kg, whereas the concentrations of  $^{40}\text{K}$  of 1 400-1 501 Bq/kg coincide with areas of an intermediate and gentle slope. This is because  $^{40}\text{K}$  is highly soluble. Any overland flow will remove the  $^{40}\text{K}$  radionuclides, in solution, from the location over which the flow occurs. Soil particles will also be removed via suspension, saltation and traction during overland flow. The overland flow from the higher lying surrounding areas will culminate in larger flow volumes that will slow down quickly and cause deposition of the particles in suspension.<sup>36</sup>

The high flow accumulation coinciding with the areas of higher concentrations is especially prominent in the area between Baviaansberg and the neighbouring Malgaskop. The area between Baviaansberg and Malgaskop indicates the highest  $^{40}\text{K}$  concentrations of 1 400-1 501 Bq/kg. This is caused by deposition of transported particles from both Baviaansberg and neighbouring Malgaskop. This deposition of particles increases the number of weathered particles containing  $^{40}\text{K}$  radionuclides that in turn increase the  $^{40}\text{K}$  concentrations. The area between Baviaansberg and Malgaskop is also associated with a gentle slope, high flow accumulation, and soil type described as “fine to coarse sandy soil, limestone, clayey sand and weathered granite”. The combination of gentle slope, high flow accumulation close to the foot of Baviaansberg and Malgaskop, as well as the ‘clayey sand’ contributes to higher  $^{40}\text{K}$  radionuclide concentrations. These factors indicate that the surrounding water will settle in this area and evaporate, thus depositing the particles in solution containing  $^{40}\text{K}$  radionuclides. However, there are areas of high flow accumulation that coincide with areas of low  $^{40}\text{K}$  concentrations. These areas also coincide with areas of gentle slope. These are areas removed from the granite outcrops where the water comes to rest after overland flow. The majority of particles transported in suspension or through traction and saltation would have been deposited before

reaching these areas, leaving only very small particles in suspension and particles in solution present in the water. Any  $^{40}\text{K}$  radionuclides that are in solution will be lost due to the high infiltration rates of the sandy soils of the area, hence contributing to a decrease in  $^{40}\text{K}$  concentrations.

The hydrological impact on  $^{232}\text{Th}$  and  $^{238}\text{U}$  are visible in figures 8.7, 8.8 and 8.13. The impact on the distribution of the concentrations of  $^{232}\text{Th}$  and  $^{238}\text{U}$  is not as great as that of  $^{40}\text{K}$  due to the fact that  $^{40}\text{K}$  is much more soluble than  $^{232}\text{Th}$  and  $^{238}\text{U}$ . This can be observed where the higher concentrations of  $^{232}\text{Th}$  and  $^{238}\text{U}$  are focused around the granite outcrops, and it shows a gradual decrease in  $^{232}\text{Th}$  and  $^{238}\text{U}$  concentrations downslope. This is due to the overland flow in the research site that gradually removes the  $^{232}\text{Th}$  and  $^{238}\text{U}$  radionuclides from the parent material. The comparison with the slope raster also show that  $^{232}\text{Th}$  and  $^{238}\text{U}$  are less soluble than  $^{40}\text{K}$ . The higher ratios of  $^{232}\text{Th}$  to  $^{40}\text{K}$  are concentrated around the areas of steep slope (granite outcrops) and that the ratio decreases downslope away from Baviaansberg. The same scenario is reflected where higher ratios of  $^{238}\text{U}$  to  $^{40}\text{K}$  are concentrated around the granite outcrops and decreased downslope. This is due to the overland flow of water that accumulates sediment with  $^{40}\text{K}$  radionuclides in suspension and in solution and deposits it further downslope from the granite outcrops. The hydrological impact on the spread of concentrations of natural radionuclides is influenced by their solubility, as was demonstrated by Ruffel et al.<sup>37</sup>

Figure 8.14 is a raster image that shows areas of spatial irregularities indicating where the Kriging interpolated values differs significantly from the measured values. It is clear that the  $^{232}\text{Th}$  results show the least discrepancies between the Kriging interpolated values and the thin plate spline interpolated values. This means that the interpolated values from Kriging and thin plate splines fall within one standard deviation from the measured values, thus the predicted values are similar to the actual measured values. The reason for this is that  $^{232}\text{Th}$  is the least soluble of the three natural radionuclides and will not be removed from its geographic position as easily as  $^{40}\text{K}$  and  $^{238}\text{U}$ . This deduction is supported by the findings of Ruffel et al.<sup>38</sup>



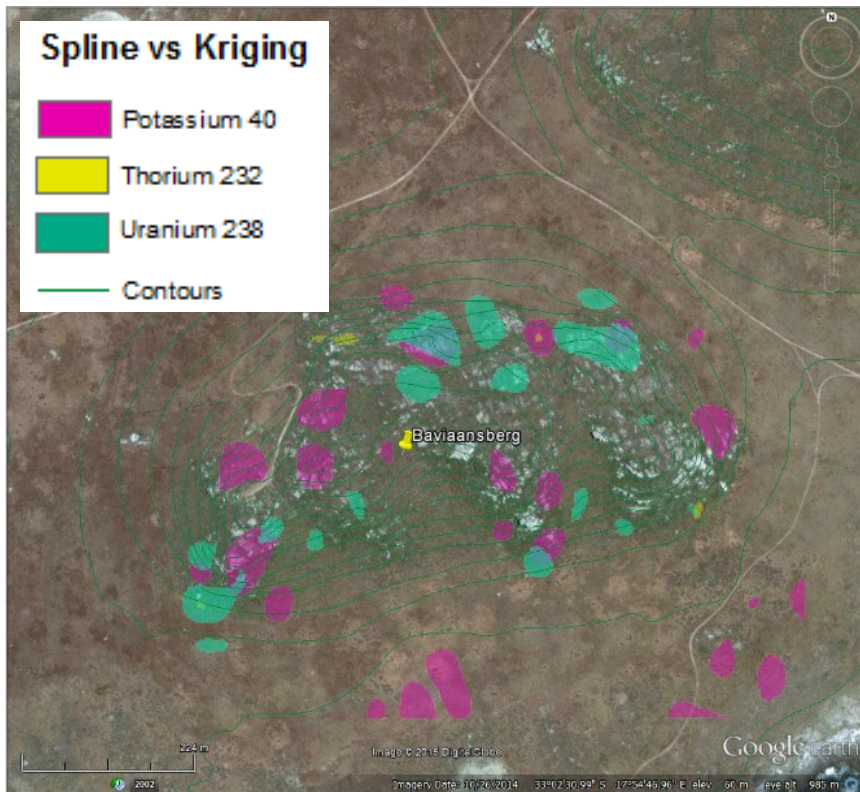


FIGURE 8.14 A Google Earth image of the research site indicating the areas with differences in values between Kriging and thin plate splines<sup>39</sup>

When comparing the flow accumulation raster (figure 8.13), the granite outcrops (figure 8.9) and the ratio of  $^{238}\text{U}$  to  $^{232}\text{Th}$  (figure 8.15) it can be seen that the areas of a ratio of one to one of  $^{238}\text{U}$  to  $^{232}\text{Th}$  correlate with the granite outcrops and with the areas of high deposition. There is also an occurrence where the ratio of the concentrations of  $^{238}\text{U}$  to  $^{232}\text{Th}$  in the areas of deposition is the same as that of the granite outcrops. The deposition that occurs in these areas is from particles containing  $^{238}\text{U}$  and  $^{232}\text{Th}$  natural radionuclides in suspension, because particles in solution will be lost due to drainage.<sup>40</sup> Particles in suspension originate from granites with a ratio of one to one  $^{238}\text{U}$  to  $^{232}\text{Th}$ , thus the areas where these particles are deposited will show the same ratio of one to one  $^{238}\text{U}$  to  $^{232}\text{Th}$ .

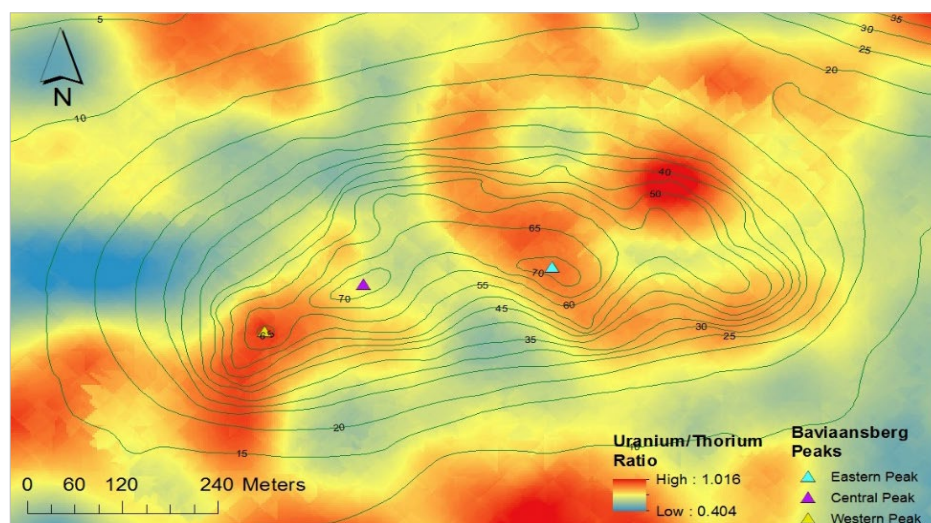


FIGURE 8.15 An image of the ratio of  $^{238}\text{U}$  to  $^{232}\text{Th}$

In figure 8.15 the valley on the southern slope between the eastern and central peak shows a ratio of  $^{238}\text{U}$  to  $^{232}\text{Th}$  of 0,54-0,66. This result supports the work of Ruffel et al.<sup>41</sup> It indicates that the  $^{238}\text{U}$  radionuclides are removed first, leaving the less soluble  $^{232}\text{Th}$  radionuclides behind. Over time the impact of Aeolian erosion becomes more prevalent in soil formation.<sup>42</sup> The impact of the Aeolian erosion results in the southern slope being steeper than the northern slope. What might have occurred over time is that the dry southerly winds deposited fine particles on the leeward side of Baviaansberg to produce the less steep northern slope.<sup>43</sup> From figure 8.16 it can be seen that the wind direction is south-east to south-west 62,4% of the time and prevails in the warm and dry months of the year. A mere 27,5% of the year the wind direction is west south-west to northerly.

The significance of the prevailing west south-westerly and northerly wind directions is the fact that these winds are associated with winter and the rainy season. The Aeolian influence of these winds will thus be less prominent because of the fairly frequent wet conditions. Goossens showed that maximum deposition of small particles occurs on the leeward side. Goossens also determined that the windward side of a hill has a steeper profile than the leeward side, due to the deposition that occurs on the leeward slopes of a hill. The impact of Aeolian erosion and deposition on the  $^{40}\text{K}$  concentrations can be seen in figure 8.6. The concentrations of  $^{40}\text{K}$  is higher on the northern slope of Baviaansberg than on the southern slope. The summer winds cause Aeolian erosion of the southern slope, the windward slope, and deposit the Aeolian eroded particles on the northern slope, the leeward slope. These deposited particles containing  $^{40}\text{K}$  radionuclides



increase the amount of  $^{40}\text{K}$  radionuclides already in the soil; they in turn increase the  $^{40}\text{K}$  concentrations. The distribution of the concentrations of  $^{40}\text{K}$  supports the research done by Goossens.<sup>44</sup> By studying the concentration distribution of  $^{40}\text{K}$  it is possible to predict the influence of Aeolian erosion around hills.  $^{232}\text{Th}$  and  $^{238}\text{U}$  showed no noticeable correlation in terms of its concentration levels and Aeolian impact.

Bezuidenhout has shown that historical human activities decrease the radiation concentrations of  $^{40}\text{K}$ .<sup>45</sup> His findings on the influence of human activities on  $^{232}\text{Th}$  and  $^{238}\text{U}$ , were however inconclusive. Figures 8.17a-c display the human activities overlay on the radioelement maps of  $^{40}\text{K}$ ,  $^{232}\text{Th}$  and  $^{238}\text{U}$ .

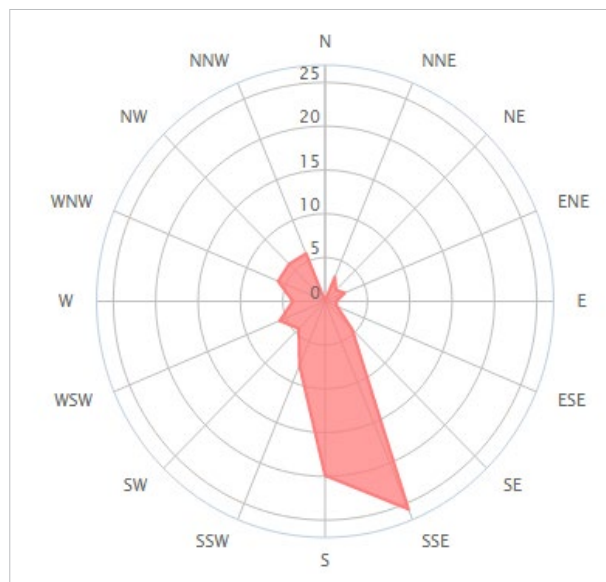
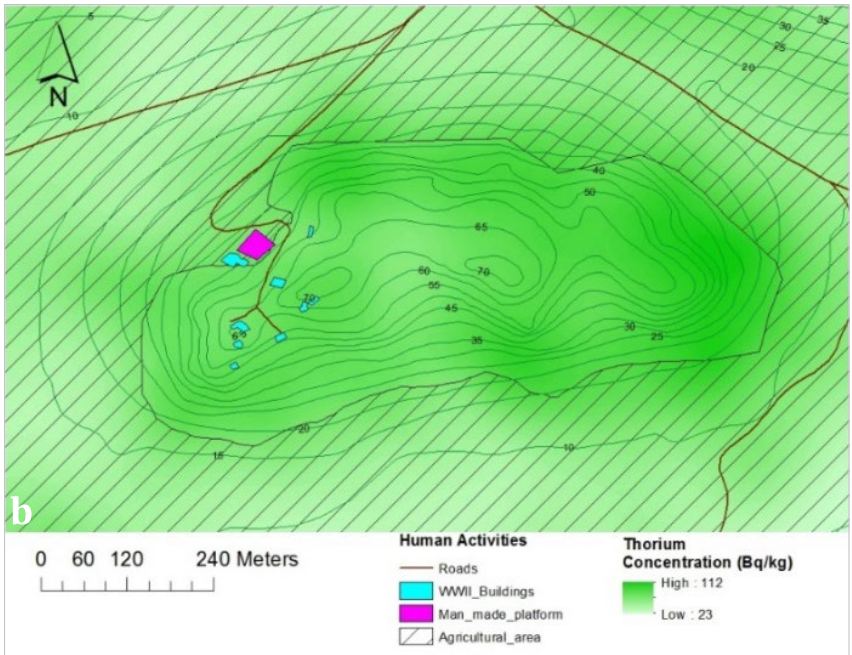
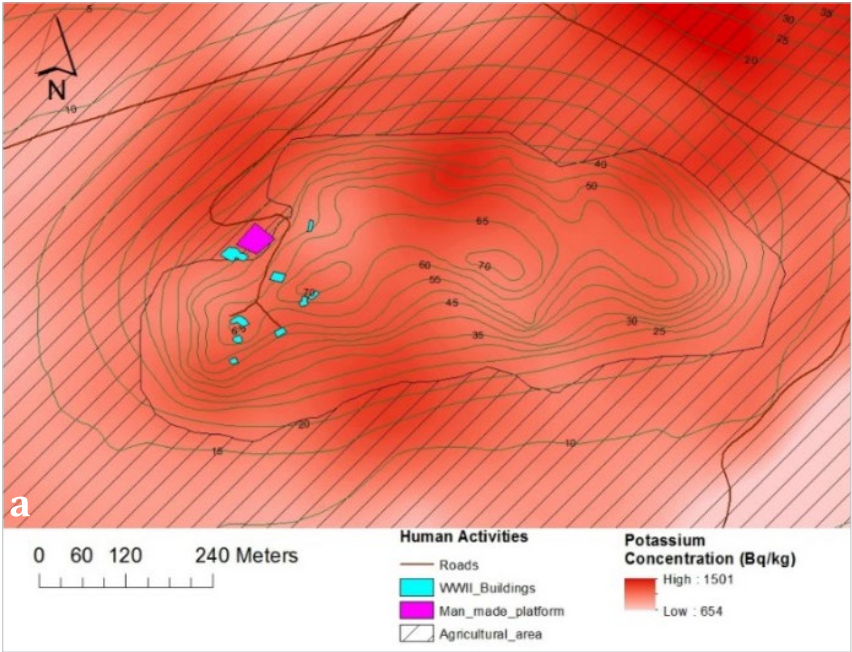


FIGURE 8.16 Wind direction distribution of the Saldanha area. Data for the observations were taken from December 2003–February 2008 daily from 07:00–19:00 local time and are represented in percentages per annum<sup>46</sup>



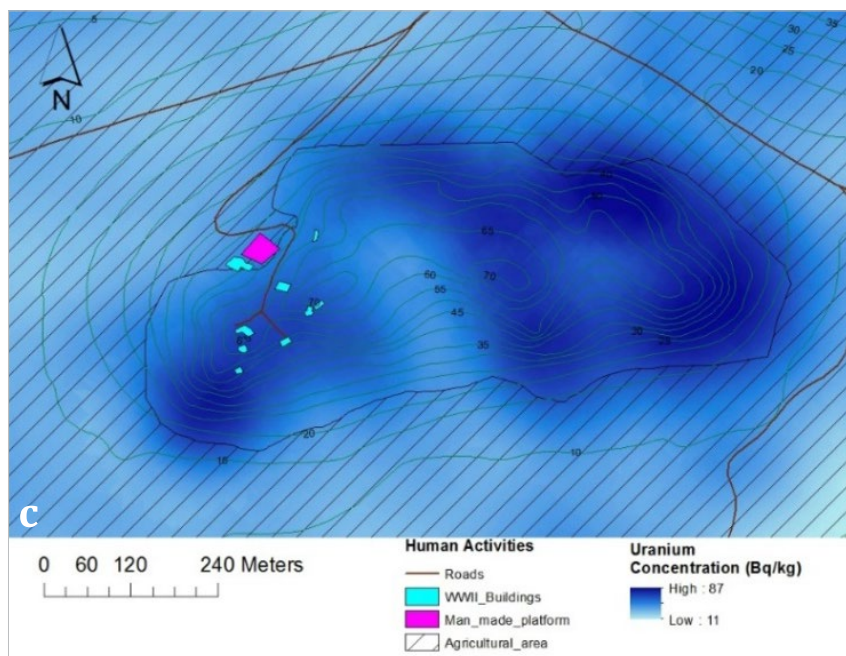


FIGURE 8.17 (a-c) Human activities as an overlay on the radioelement maps of  $^{40}\text{K}$ ,  $^{232}\text{Th}$  and  $^{238}\text{U}$

In figure 8.17a the areas around the Second World War buildings and man-made platform show lower  $^{40}\text{K}$  concentrations than the surrounding areas. This might be due to the human activities in and around these areas. However, there is no conclusive evidence of this proposition. More measurements of this specific areas need to be taken to confirm or negate a possible relationship between human activities and potassium levels. Figures 8.17b and c also show no conclusive evidence of a positive relation between the Second World War buildings and man-made platform, and the concentrations of  $^{232}\text{Th}$  and  $^{238}\text{U}$ . These results corroborate the findings of Bezuidenhout, but should be studied further in order to firmly establish further relationships or the absence thereof.<sup>47</sup>

There is, however, an established relationship between human agricultural activities and the concentrations of  $^{232}\text{Th}$  and  $^{238}\text{U}$ , according to figures 8.18 and 8.19. The concentrations of  $^{232}\text{Th}$  and  $^{238}\text{U}$  decrease downslope from the boundaries of the agricultural areas. This is not conclusive, as the areas above the agricultural boundaries are also the areas that were not conducive to agriculture, i.e. rocky areas with granite outcrops. These rocky outcrops also influence the concentrations of  $^{232}\text{Th}$  and  $^{238}\text{U}$ . However, figures 8.18 and 8.19 support the theory that human activities influence the concentrations of  $^{40}\text{K}$ .



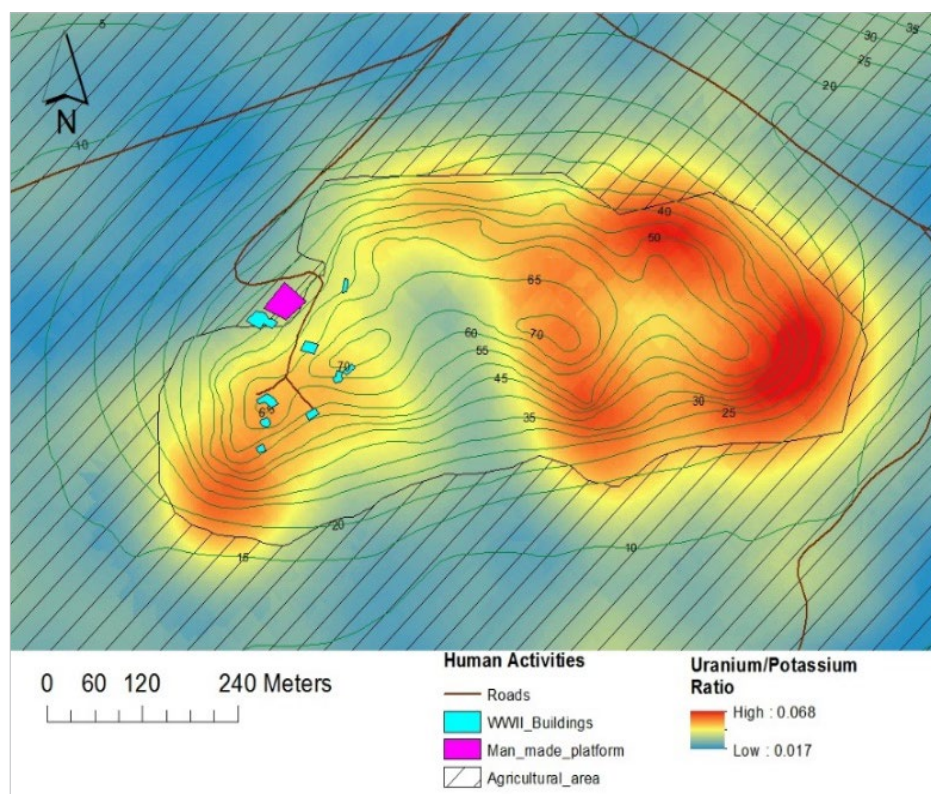


FIGURE 8.18 Human activities as overlays on the maps that indicate the ratios of  $^{232}\text{Th}/^{40}\text{K}$

The areas on and surrounding the Second World War buildings and man-made platform show a lower ratio, 0,050-0,057, of  $^{232}\text{Th}$  to  $^{40}\text{K}$  in comparison to the areas on the same contours with the same slope profile, 0,070-0,092. There is also a similar relationship between the Second World War buildings and man-made platform to the ratio of  $^{40}\text{K}$  to  $^{238}\text{U}$ , as seen in figure 8.19. However, this relationship is not as prominent as the relationship between human activities and the ratio of  $^{232}\text{Th}$  to  $^{40}\text{K}$  (figure 8.18). Blue tinted areas in figures 8.18 and 8.19 are areas where the ratio of  $^{232}\text{Th}$  and  $^{238}\text{U}$  to  $^{40}\text{K}$  are lowest, thus indicating lower concentrations of  $^{40}\text{K}$  in comparison to  $^{232}\text{Th}$  and  $^{238}\text{U}$ . This is another indication that the  $^{40}\text{K}$  radionuclides are removed more easily than the less soluble  $^{232}\text{Th}$  and  $^{238}\text{U}$  radionuclides, once again supporting the research of Ruffel et al.<sup>48</sup>

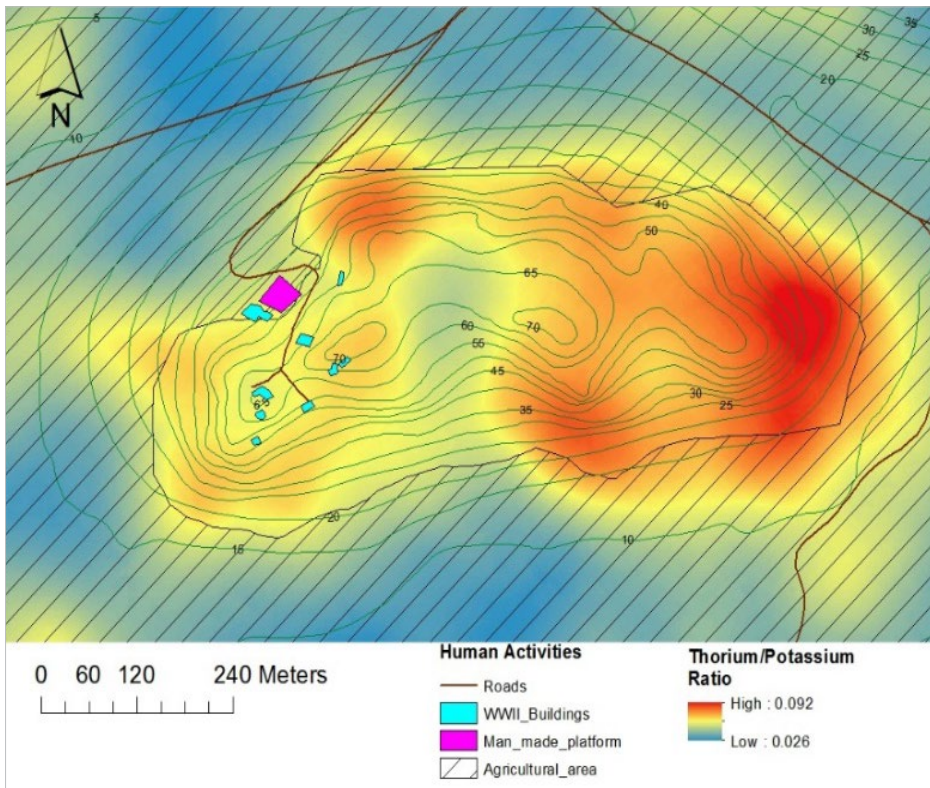


FIGURE 8.19 Human activities as overlays on the maps that indicate the ratios of  $^{238}\text{U}/^{40}\text{K}$

## Conclusion

The natural radionuclides  $^{40}\text{K}$ ,  $^{232}\text{Th}$  and  $^{238}\text{U}$  are ever present in the natural environment, but the concentrations differ measurably between different rock and soil types and geographic locations. Granites have higher concentrations of natural radiation than most other rock types. This applies to soil originating from these granites, as well. The distribution of soil and therefore natural radiation is highly dependent on the geographic factors unique to an area. The results have shown that the geology of an area influences the distribution of  $^{40}\text{K}$ ,  $^{232}\text{Th}$  and  $^{238}\text{U}$  concentrations where high concentration levels were measured close to and on top of granite outcrops on Baviaansberg in Saldanha Bay. The slope of a hill influences the distribution of  $^{40}\text{K}$  to a greater extent than  $^{232}\text{Th}$  and  $^{238}\text{U}$  because  $^{40}\text{K}$  is more soluble than  $^{232}\text{Th}$  and  $^{238}\text{U}$ . The steeper, southern, slope of Baviaansberg has shown lower concentration levels than the less steep northern slope.

Soil composition contributes to the distribution of the concentrations of natural radiation where soil closer to granite outcrops has higher concentrations of  $^{40}\text{K}$ ,  $^{232}\text{Th}$  and  $^{238}\text{U}$ . Finer-grained sandy soils further from granite outcrops also show a drop in concentrations of  $^{40}\text{K}$ ,  $^{232}\text{Th}$  and  $^{238}\text{U}$  due to their high infiltration rates. The further soil is transported away from its parent material, the more dispersed the soil particles become. More external materials, such as dead organic materials or marine deposits, are also added to its composition as the distance away from the parent material increases. This changes the composition of the soil, as well as the natural radiation signature of the soil. The hydrology of an area influences the distribution of  $^{40}\text{K}$  to a greater extent than that of  $^{232}\text{Th}$  and  $^{238}\text{U}$  due to  $^{40}\text{K}$  being more soluble than  $^{232}\text{Th}$  and  $^{238}\text{U}$ . Wind also plays a role in the general distribution patterns of natural radionuclides. This is particularly visible in the distribution of  $^{40}\text{K}$  concentrations where the leeward side of Baviaansberg hosts a greater number of areas of high  $^{40}\text{K}$  concentrations than its windward side.

The results of this study revealed that human activities probably also play a role in determining the distribution of natural radiation, again to a greater extent in the distribution of  $^{40}\text{K}$ . However, these relationships could not be established beyond doubt and will have to be studied further, especially since all relevant geographic factors have a collective impact on the spread of natural radiation within an area.

## ENDNOTES AND REFERENCES

1. Wang, Z. 2002. Natural radiation environment in China. *International Congress Series*, 1225:39-46. [https://doi.org/10.1016/S0531-5131\(01\)00548-9](https://doi.org/10.1016/S0531-5131(01)00548-9)
2. Montes, M.L.; Mercader R.C.; Taylor, M.A.; Runco, J. & Desimoni, J. 2012. Assessment of natural radioactivity levels and their relationship with soil characteristics in undisturbed soils of the northeast of Buenos Aires province, Argentina. *Journal of Environmental Radioactivity*, 105:30-39. <https://doi.org/10.1016/j.jenvrad.2011.09.014>
3. Arafa, W. 2004. Specific activity and hazards of granite samples collected from the Eastern Desert of Egypt. *Journal of Environmental Radioactivity*, 75:315-327. <https://doi.org/10.1016/j.jenvrad.2004.01.004>
4. Llope, W.J. 2011. Activity concentrations and dose rates from decorative granite countertops. *Journal of Environmental Radioactivity*, 102:620-629. <https://doi.org/10.1016/j.jenvrad.2011.03.012>
5. Scheepers, R. & Armstrong, R. 2002. New U-PB SHRIMP zircon ages of the Cape Granite Suite: Implications for the magmatic evolution of the Saldania Belt. *South African Journal of Geology*, 105(3):241-256. <https://doi.org/10.2113/1050241>
6. Tzortzis, M.; Svoukis, E. & Tsetos, H. 2004. A comprehensive study of natural gamma radioactivity levels and associated dose rates from surface soils in Cyprus. *Radiation Protection Dosimetry*, 109(3):217-224. <https://doi.org/10.1093/rpd/nch300>

7. Franceschini, G. & Compton, J.S. 2004. Aeolian and marine deposits of the Tabakbaai Quarry area, Western Cape, South Africa. *South African Journal of Geology*, 107:619-632.  
<https://doi.org/10.2113/gssaig.107.4.619>
8. Provincial Government of the Western Cape. 2005. *Western Cape provincial spatial development framework: The Western Cape province today and tomorrow*. Cape Town: Department of Environmental Affairs and Development Planning (Statutory report).
9. Google Earth. Saldanha 33°02'31.28"S and 17°54'47.14"E. 2016. [Accessed 3 November 2016].
10. Bezuidenhout, J. 2012. Mapping of historical human activities in the Saldanha Bay Military Area by using *in situ*  $\gamma$ -ray photon measurements. *Scientia Militaria*, 40(2):1-24.  
<https://doi.org/10.5787/40-2-998>
11. Ibid.
12. CSIR. 2014. *Environmental screening study for a proposed LNG terminal at Saldanha and associated pipeline infrastructure to Atlantis and Cape Town, Western Cape, South Africa*. Prepared for the Western Cape Government, Department of Economic Development and Tourism. Report Number CSIR/CAS/EMS/ER/2014/0012/B. Stellenbosch: Council for Scientific and Industrial Research.
13. Bezuidenhout, 2012, op. cit.
14. FLIR. 2015. [Online]: <http://www.flir.com/threatdetection/display/?id=65349>  
[Accessed 1 December 2015].
15. Trimble. 2015. [Online]: [http://www.trimble.com/mappingGIS/yuma2\\_rugged\\_tablet.aspx?tab=Technical\\_Support](http://www.trimble.com/mappingGIS/yuma2_rugged_tablet.aspx?tab=Technical_Support) [Accessed 1 December 2015].
16. Noncolela, S.P. 2011. *Calibration of a NaI(Tl) detector for low level counting of naturally occurring radionuclides in soil*. Master's thesis. University of the Western Cape, Physics Department.
17. Bezuidenhout, J. 2015b. Testing and implementation of a transportable and robust radio-element mapping system. *South African Journal of Science*, 111(9/10): 153-159.  
<https://doi.org/10.17159/sajs.2015/20140350>
18. Congalton, R.G. & Green, K. 2008. *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices*. 2<sup>nd</sup> ed. Boca Raton: CRC Press. <https://doi.org/10.1201/9781420055139>
19. International Atomic Energy Agency (IAEA). 2003. *Guidelines for radioelement mapping using  $\gamma$ -ray photon spectrometry data*. Vienna: International Atomic Energy Agency (IAEA-TECDOC-1363).
20. South Africa. 1997. *South Africa 1:10 000 orthophoto map series 3317BB 3 & 4 & 9 Saldanha*. 3<sup>rd</sup> ed. (Map). Cape Town: Chief Directorate of Surveys and Mapping.
21. Stanford School of Medicine. Changing variables from continuous to categorical. 2004. Stanford University. [Online]: <http://cliomods.stanford.edu/trailmaps/sample/cohort/changingVariables/index.html> [Accessed 1 November 2016].
22. Ramli, A.T. 1997. Environmental terrestrial gamma radiation dose and its relationship with soil type and underlying geological formations in Pontian District, Malaysia. *Applied Radiation and Isotopes*, 48(3):407-412. [https://doi.org/10.1016/S0969-8043\(96\)00264-3](https://doi.org/10.1016/S0969-8043(96)00264-3)
23. Hess, D. 2014. *McKnight's Physical Geography: A Landscape Appreciation*. 11<sup>th</sup> ed. New Jersey: Pearson Education, Inc.

24. Marshak, S. 2001. *Earth: Portrait of a planet*. New York: W.W. Norton & Company.
25. Hess, 2014, op. cit.
26. Marshak, 2001, op. cit.
27. Sharma, op. cit.
28. Ruffel, A.; McKinley, J.M.; Lloyd, C.D. & Graham, C. 2006. Th/K and T/U ratios from spectral gamma-ray surveys improve the mapped definition of subsurface structures. *Journal of Environmental & Engineering Geophysics*, 11(1):53-61. <https://doi.org/10.2113/JEEG11.1.53>
29. Ruffel, 2006, op. cit.
30. Ramli, 2006, op. cit.
31. Greyling, A.W. 2001. 'n Geografiese inligtingstelsel as bestuurhulpmiddel vir die SAS SALDANHA natuurresewaat. Honours research report. Saldanha: Stellenbosch University, Faculty Military Science, School for Geospatial Studies and Information Systems, Department of Military Geography.
32. Ahmad, T.R. 1997. Environmental terrestrial gamma radiation dose and its relationship with soil type and underlying geological formations in Pontian District, Malaysia. *Applied Radiation and Isotopes*, 48(3):407-417.
33. Strahler, A.H. & Strahler, A.N. 1992. *Modern physical geography*. 4<sup>th</sup> ed. New York: John Wiley & Sons.
34. Marshak, 2001, op. cit.
35. Chang, K. 2012. *Introduction to Geographic Information Systems*. 6<sup>th</sup> ed. New York: McGraw-Hill.
36. Hess, 2014, op. cit.
37. Ruffel, 2006, op. cit.
38. Ibid.
39. Google Earth, op. cit.
40. Michel, J. 1984. Redistribution of uranium and thorium series isotopes during isovolumetric weathering of granite. *Geochimica et Cosmochimica Acta*, 48:1249-1255. [https://doi.org/10.1016/0016-7037\(84\)90059-0](https://doi.org/10.1016/0016-7037(84)90059-0)
41. Ruffel, 2006, op. cit.
42. Hess, 2014, op. cit.
43. Goossens, D. 2006. Aeolian deposition of dust over hills: The effect of dust grain size on the deposition pattern. *Earth Surface Processes and Landforms*, 31:762-776. <https://doi.org/10.1002/esp.1272>
44. Provincial Government of the Western Cape, 2005, op. cit.
45. Goossens, 2006, op. cit.
46. Bezuidenhout, 2012 or 2015, op. cit.
47. Ibid.
48. Ruffel, 2006, op. cit.